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THE INEFFECTIVENESS OF PRESENT-DAY RADIOLOGY IN DIAGNOSIS OF CARCINOMA OF THE CARDIAC END OF THE STOMACH, WITH SUGGESTIONS FOR IMPROVEMENT.[1]

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A REVIEW of ten patients seen recently, with carcinoma of the cardiac end of the stomach, provides food for thought. Two were operable. Two others were on the borderline (requiring total gastrectomy, splenectomy and hemi-pancreatectomy). Three were found at laparotomy to be inoperable. Three were no doubt inoperable and did not come to operation. This compares badly with the operability rate of Churchill and Sweet, who found fifteen among twenty patients operable. Our poor operability rate is not due to a lack of operative determination. The stomach is always removed, unless it is fixed by gross carcinoma to structures which are themselves irremovable. The poor operability rate was due to late diagnosis. Late diagnosis may be caused by the asymptomatic development of the growth or by the failure of the patient to report. These ten patients had symptoms and they reported. The clinician suspected carcinoma of the stomach in each case, and referred the patient for radiological examination. In only one instance (Case II) was the carcinoma recognized by the radiologist. In the other nine, negative reports were returned, sometimes after repeated examinations by different radiologists. All too frequently these negative reports destroy all chance of an early diagnosis. They seem to hypnotize the clinician, so that clinical sword and buckler fall from his grasp.

Six patients were seen in private practice and were examined by different radiologists. The others were examined at different hospitals.

It is instructive to retrace our steps in the light of after-knowledge and to review the earlier efforts at diagnosis.

CASE I.—Mr. B., aged fifty-five years, suffered from general ill health, diarrhœa and achlorhydria. He had a carcinoma, probably operable. On October 16, 1941, the radiologist reported the stomach to be normal. The films are not available. By February 16, 1943, the carcinoma was huge, involving most of the stomach, the spleen and the pancreas, and the radiologist's second report was: "The stomach is of a cup and spill type with a large upper loculus. There is a good deal of delay in the passage of the meal from the œsophagus into the stomach. I could not see any definite organic lesion to account for this, but owing to the large upper loculus I could not visualize the upper part of the stomach very well and I cannot confidently exclude carcinoma of the upper third of the stomach."

[1] Accepted for publication on June 17, 1948.

On February 23, 1943, the radiologist's third report was: "The appearance does not suggest carcinoma of the œsophagus, unless there is a small lesion right at the cardiac sphincter. I cannot visualize the cardiac end of the stomach. There may be a small carcinoma in this situation."

After one negative and two equivocal reports the radiologist, by request and for the first time, took skiagrams with the patient in the supine and rotated positions, with the following result. Radiologist's fourth report: "There is a carcinoma involving the cardiac end of the stomach" (March 9, 1943).

The cardiac end of the stomach could not be visualized in the second and third examinations with the patient in the upright position, because it was so full of neoplasm. Use of the supine position would have ensured a true interpretation.

FIGURE I. Case III. Prone position, shown by air at cardiac end. Unreported carcinoma between arrows. Lesser curvature ulcer lower down. Error due to neglect of supine position.

CASE III.—Mr. G., aged fifty years, had a carcinoma at the cardiac end of the stomach, with penetrating non-malignant ulcer of the lesser curvature. The radiologist's first report, on April 15, 1946, was: "Penetrating ulcer on lesser curvature" (Figure I). There was no mention of carcinoma. But the patient's pain of years' standing had recently altered in rhythm, and he had lost weight. He was sent back to the radiologist with a request for an examination with the patient in supine and rotated positions. The radiologist's second report, on April 27, 1946, was: "There is an area at the cardiac end which does not fill constantly when the patient was in various positions, upright, Trendelenburg, right and left oblique. Appearance very suggestive, but not definite, of neoplasm." The presence of neoplasm was confirmed at the operation.

CASE IV.—Mr. P., aged forty-three years, a schoolteacher, had advanced carcinoma of the cardiac end of the stomach. He had no symptoms till he fell off a bus and dislocated his shoulder. Then he experienced epigastric pain, which persisted. The radiologist's report was as follows: "Alimentary tract normal." Films are not available. He was treated as suffering from gastric neurosis for eight months. He was then admitted to hospital with "blackouts". His hæmoglobin value was 50%, the red blood cells numbered 2,000,000 per cubic millimetre, and he had lost one and a half stone in weight. At operation the carcinoma was found to be large and fixed to retroperitoneal structures.

CASE V.—Mrs. B., aged fifty-two years, had advanced carcinoma of the cardiac end of the stomach, probably inoperable. On July 13, 1945, the radiologist reported: "Organic lesion of cardiac third, due to either healed ulcer with adhesions or to a polypus" (Figure IIA). In spite of the rarity of these conditions, no attempt was made to check the finding with the patient in the supine position. Had this been done, the nature of the filling defect could not have been mistaken. On the basis of this report by a senior radiologist, the patient was treated for seven months with antacids.

Figure IIB shows a supine view just before operation. Note the failure of the cardiac end to balloon out. The condition was hopelessly inoperable.

CASE VI.—Mr. R., aged fifty-four years, on October 19, 1945, was under treatment for *achylia gastrica*. He had a huge carcinoma of the cardiac end of the stomach. The radiologist's report was: "The stomach was high and hypertonic with a degree of pylorospasm rendering the bulb at no time visible. I would suggest reexamination after a course of antispasmodic treatment" (Figure III). The patient was not examined in the supine position. Had this been done, a filling defect at the cardiac end, seen in Figure III, would have appeared as a definite carcinoma and would probably have been detected by the radiologist. On February 7, 1946, the radiologist's second report, after he had, by request, examined the patient supine, was: "There is a marked induration of the lesser curvature of the stomach and the appearances are strongly suggestive of neoplasm in this area."

FIGURE IIA. Case V. Large carcinoma at cardiac end, reported as "adhesions or polypus". Error due to use of only the upright position.

CASE VII.—Mrs. L., aged sixty-three years, on December 12, 1946, had the classical signs and symptoms of advanced

FIGURE IIB. Case V. Failure of the cardiac end to balloon out, in the supine position. A sign of advanced carcinoma.

carcinoma of the stomach. The radiologist's report was: "Stomach and duodenum normal. Small calcified hydatid cyst of the liver" (see Figures IVA and IVB). The patient was standing or prone throughout the examination. There was no supine view. The patient was sent back to the radiologist with a request to be examined in the supine and rotated positions. A second set of skiagrams, dated January 9, 1947, shows the typical filling defect of advanced carcinoma of the cardiac end (Figure IVC).

CASE VIII.—Mrs. McG. had marked weakness and severe pain around the left costal margin, with a profound anæmia. She was investigated in a neighbouring State. The radiologist pronounced the stomach normal and she was advised to come to Sydney for a holiday. On arrival she was so weak that she was admitted to hospital. A physician secured a second radiological examination of the stomach. Films were taken with the patient in the prone position only (Figure VA) and the stomach was again reported normal (November 5, 1947). A third radiological examination was now arranged (November 16, 1947), with the request that the patient should be examined supine. When this was done a carcinoma at the cardiac end was revealed (Figure VB). At operation the growth was found to be inoperable, as large as a fœtal head, involving the posterior gastric wall, and infiltrating the kidney, pancreas and spleen. The spleen appeared like a small cap fixed upon it.

FIGURE III. Case VI. Large carcinoma at cardiac end, shown by obliquity of upper medial part of barium shadow. Unrecognized because of neglect of supine position. Note gas at cardiac end.

Skiagrams giving a lateral view of the stomach with the patient supine would have revealed this growth at a much earlier stage. Such skiagrams were taken after the operation. The films themselves are not satisfactory for reproduction, but a tracing of one is shown (Figure Vc). The cardiac end has failed to balloon out and looks like a piece of chewed sugarcane instead of like a gourd.

FIGURE IVA. Case VII. Patient standing. No sign of gastric lesion.

CASE IX.—Mr. G., aged sixty-seven years, went to his physician complaining of epigastric pain and vomiting. The radiologist, on March 26, 1947, reported that the stomach was normal, and the patient was sent away. But all the films show a small filling defect at the cardiac end (Figure VIA). It was subsequently learnt from this radiologist that he did not believe the filling defect to be significant because it varied from film to film. In December, 1947, the patient went to a second physician, who sent him to a second radiologist with a request to examaine the patient supine. This radiologist reported a cascade stomach and gastrospasm, which in his opinion were due to ulcer, and he suggested antispasmodics. None of the films was taken with the patient in the supine position, but one was labelled "supine" (Figure VIB). The label is belied by the gas at the cardiac end, with the horizontal fluid level beneath. On January 7, 1948, the patient was admitted to hospital and a third radiological examination was made. The film with the patient in the supine position showed the defective ballooning typical of advanced carcinoma. At operation the carcinoma was found infiltrating the pancreas. The whole stomach was removed with the spleen and half the pancreas.

FIGURE IVB. Case VII. Prone, oblique. No sign of gastric lesion, except minor irregularity of lesser curvature at cardiac end, unnoticed by radiologist.

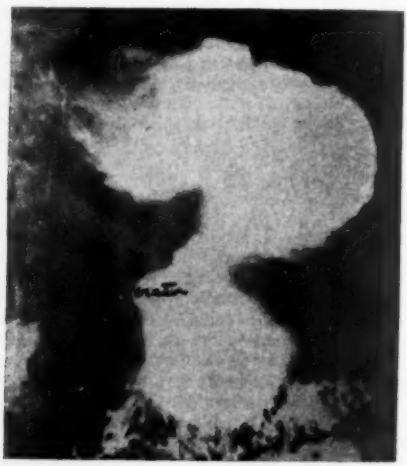

FIGURE IVC. Case VII. Films taken three weeks later with patient in supine position reveal huge malignant ulcer at cardiac end, unrevealed at first examination.

CASE X.—Mrs. Y., aged sixty-six years, had symptoms of carcinoma of the stomach. In November, 1947, the stomach was examined radiologically at a country centre in the southern district of New South Wales and reported to be normal. The films are not available. On February 3, 1948, a similar report was secured at a country centre

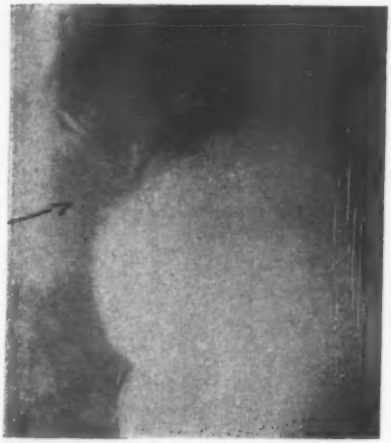

FIGURE VA. Case VIII. Advanced carcinoma of cardiac end (posterior wall), concealed in prone position and missed by radiologists.

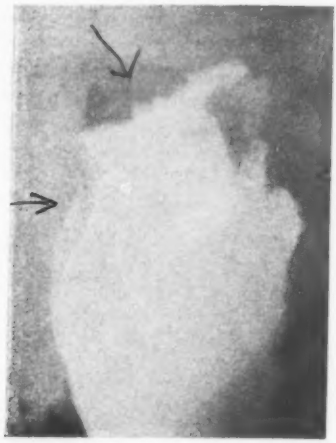

FIGURE VB. Case VIII. Advanced carcinoma of cardiac end (posterior wall), revealed in supine position.

in the western district. For the films (and, of course, for the screening), the standing position only was used. On April 22, 1948, œsophagoscopy by Dr. Lance Corner revealed food in the œsophagus, but no œsophageal lesion. The patient was sent to a third radiologist, with suggestions about the examination of the cardiac end. The report came back: "There is an extensive and advanced carcinoma of the stomach. This has apparently commenced in the cardiac region and has extended to involve practically the whole of the body of the stomach."

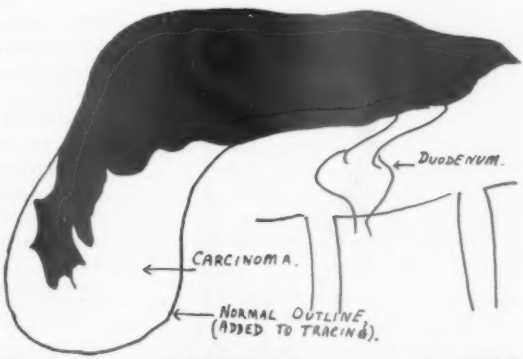

FIGURE VC. Case VIII. Tracing from film of supine lateral view, showing advanced carcinoma, which was hidden in the prone postero-anterior view, and thus overlooked at two radiological examinations.

RADIOLOGICAL TECHNIQUE: AN IMPROVED ROUTINE.

A study in retrospect of these patients suggests improvements in radiological technique. A suggested routine is as follows.

The Œsophageal Jet.

The patient is examined with the fluoroscope in the standing position. The bolus is observed as it enters the stomach. It leaves the œsophagus as a jet, passes down the cardiac end of the *Magenstrasse* and spreads out in the body of the stomach, gradually settling to the most dependent part. The jet may be delayed by a lesion at the œsophageal orifice and it may be distorted by a proliferative lesion at the cardiac end of the *Magenstrasse* (at A in Figure VII). It will not reveal a lesion of the fundus (at B in Figure VII).

The Mucosal Pattern.

The mucosal pattern is studied after the first few mouthfuls of meal. In order to smear with barium the fundus mucosa, the emulsion is pressed upwards with the hand, or it may be necessary to place the patient supine for a moment.

FIGURE VIA. Case IX. Carcinoma of cardiac end, not reported by first radiologist.

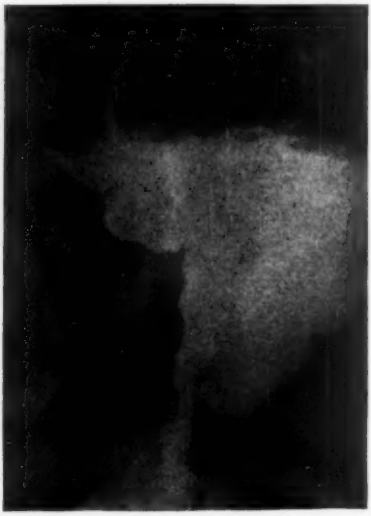

FIGURE VIB. Carcinoma nine months later, reported by a second radiologist as "cascade stomach", probably due to ulcer. In spite of request by clinician, no supine views were taken, but one film, this one, was labelled "supine".

Sliding pressure is made with the finger tips on the abdominal wall, the softness and pliability of the wall of the stomach are noted, and the rugæ, normally sinuous and parallel, are studied. These features are not so helpful at the cardiac end, because this part is inaccessible to palpation and the rugæ at the fundus lose their simple parallel pattern. On the greater curvature they are seen, on end, as they pass spirally from anterior to posterior wall. They may simulate an early carcinoma. The upright lateral view (*quod vide*) helps to prevent error.

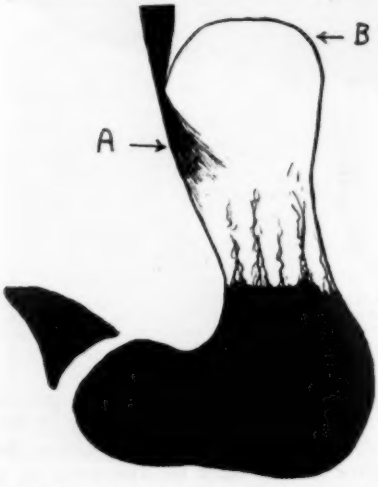

FIGURE VII. The œsophageal jet. This may reveal a lesion at A, but not at B.

The Splashing Manœuvre.

The patient swallows still more of the meal, which soon forms a puddle in the most dependent part of the stomach. Gradually the horizontal part of the stomach fills, and finally the upper level of the meal rises in the vertical part, gradually approaching the upper pole. But, as a rule, the

cardiac end and fundus do not fill well when the patient is standing. A volume of air, the *Magenblase*, remains above the barium. The radiologist endeavours to fill the inaccessible upper pole by pressing upon the lower part of the stomach, so that barium is forced upwards and perhaps held for a moment at the cardiac end. But the air cannot be thoroughly displaced and therefore the cardiac end cannot be thoroughly filled. The ineffectiveness of this method is made clear in the cases here described.

The Upright Position.

The upright position is the position most used by radiologists, so there is no need to describe it further, except to point out that the lateral view is not sufficiently used. If it were, the error of reporting a posterior-wall, cardiac-end carcinoma as a "cascade" or "cup-and-spill" stomach would be more often avoided. Figure VIII shows a tracing of the lateral upright view. The rugæ are not always so well shown.

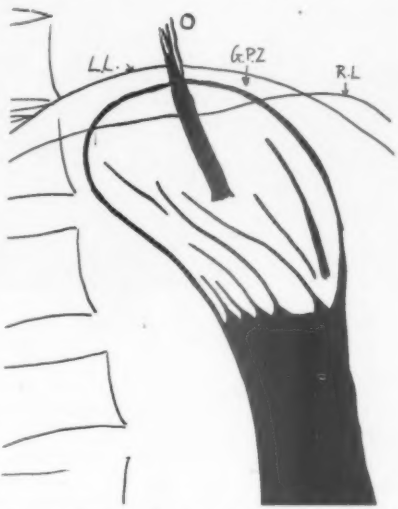

FIGURE VIII. Tracing of film of upright lateral view. O = œsophagus; L.L. = left lobe of diaphragm; R.L. = right lobe of diaphragm; G.P.Z. = gastro-phrenic zone.

The Supine Position.

The cardiac end of the stomach lies posteriorly and the pyloric end anteriorly in the abdomen, so that the long axis of the cardiac end of the stomach is directed downwards and forwards (Figure Vc). This obliquity is slight in the hyposthenic but well marked in the sthenic patient. It is therefore clear that the meal can thoroughly fill and outline the upper part of the stomach only when the patient is supine. Thorough filling is important for this part of the examination. Partial filling may simulate a carcinoma. The gas passes from the cardiac to the pyloric end. The shift of the gas helps us to identify the films taken with the patient in the supine position. Neglect of this position, which is usual, results in the missing of many lesions, not only on the posterior wall and at the cardiac end, but also on the lesser curvature. Diaphragmatic hernia is similarly overlooked. These other conditions are discussed more fully in *The Medical Journal of Australia* (May 15, 1948, page 609).

In the supine position foreshortening of the gastric shadow occurs in the antero-posterior view. This is due partly to an actual shortening of the stomach and partly to an apparent shortening or optical distortion caused by the obliquity of the cardiac end. In hyposthenics the first and in sthenics the second is the chief factor. The second factor, the apparent shortening, can be met by a downward tilt of the tube so that the central ray is perpendicular to a plane bisecting the angle between the horizontal plane and the long axis of the cardiac end. This method is used to overcome the similar problem in dental radiology. Figure IX shows the supine view with a 25° downward tilt of the central ray.

The cardiac end of the stomach passing downwards and forwards meets at an angle the pyloric end, which passes in a loop from left to right in front

of the spine. The angle at which these two parts meet is variable. When the patient is supine the barium meal tends to pool in the two main parts, separated by the angle. These two separate pools are best seen in the lateral supine view, and they are connected by a shallow gutter corresponding with the angle. In some patients the angle is acute and the separation of the two pools well marked (Figure X). In others the angle is obtuse and the separation less well marked (Figure XII). The connecting gutter often appears in the antero-posterior supine view as a filling defect, the angular gap, which marks the lower end of the cardiac part of the stomach. The gap can be easily distinguished from a carcinoma because the normal parallel rugæ can be seen as they pass from the upper to the lower pool (see Figure IX).

FIGURE IX. Normal antero-posterior supine view, with 25° downward tilt of central ray.

The Gastro-Phrenic Zone.—The supine position has a further advantage when the stomach is well filled. The fundus then becomes well distended and the rugæ smoothed out, and the gastric shadow is pressed up against the diaphragm. The barium in the fundus is now separated from the lung shadow only by the gastric wall and diaphragm. An evenly graded gap, about 3·0 millimetres wide at its centre, slightly wider at its medial and lateral ends, is seen between the barium and the lung shadow. This gap, the gastro-phrenic zone, should be carefully studied in antero-posterior and lateral skiagrams (see Figures IX, X, XII *et cetera*). Any thickening or irregularity should be considered due to a gastric carcinoma until proved otherwise. This sign, like all others used in radiology, has its fallacies and limitations, but nevertheless it is very valuable. The spleen or liver may intervene between fundus and diaphragm

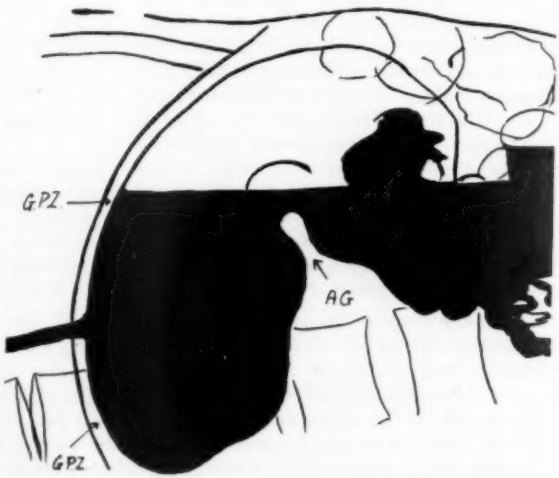

FIGURE X. Tracing from film of supine lateral view of acutely angled stomach. A.G. = angular gap; G.P.Z = gastro-phrenic zone.

to an unusual degree and thus provide a widening of the zone at either extremity; but the outline of the barium in the stomach remains relatively smooth. When a carcinoma intervenes the gastric shadow usually becomes irregular, either shaggy, dentate (Figures VB and VC) or craggy (Figures IIB and IVC). Moreover, in some films the spleen or liver can be clearly seen thus easily obviating error.

The Supine Lateral View.

It is hard to understand that lateral views are accepted as necessary in examination of nearly all parts of the body but have not been used for the cardiac end of the stomach. Perhaps the explanation lies in the limited

FIGURE XIA. Penetrating ulcer of posterior wall, revealed in supine antero-posterior view.

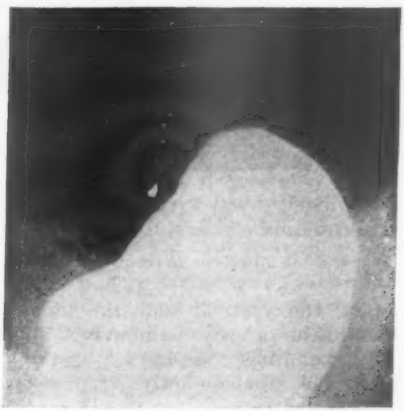

FIGURE XIB. Penetrating ulcer of posterior wall, concealed in prone postero-anterior view.

capacity of the old types of X-ray apparatus. The necessity for lateral views is made clear by Figure X. An early lesion growing from the part of the posterior wall in relationship to the upper pole of the kidney would be obscured in an antero-posterior film but could be revealed in a lateral one. The lateral view grows in importance when it is remembered that the cardiac end is inaccessible to palpation. Figure VC affords an example of the use of this view of an advanced growth. I have not yet been able to secure an example in an early stage.

In the supine position the normal stomach resembles a gourd of the Canada crook-neck type, the cardiac end being ballooned out to form the broadest part, as seen in antero-posterior or lateral films. The failure to balloon in the antero-posterior view can be seen in Figure IIB. In Figure VC it can be seen in a lateral view. This sign is of little importance in the search for an early growth, but attention is drawn to it here because even advanced growths in this part are usually overlooked and are often called "cascade" or "cup-and-spill" stomachs. The lateral view should be of great help in differentiation. The gastro-phrenic zone should also be studied in this view, sometimes leading from spine to sternum.

The pancreas sometimes causes an indentation in the posterior wall, both in the supine lateral and upright lateral views, but it has a smooth, well-defined outline.

Tilting.

It is possible that a small lesion at the cardiac end may be concealed or smothered by the mass of meal when the patient is supine, and this possibility has been advanced as an argument against the use of the supine position. But I have never seen a carcinoma or any other lesion completely smothered by the mass of meal when the patient is supine. Recently, however, a submucous, non-malignant tumour was partly obscured when the patient was in the supine position. In order to minimize the tendency to "smothering", the examination should be conducted with the table tilted to varying degree between the vertical and the horizontal. The modern table is designed to make this an easy manœuvre. The tendency is also minimized if the patient is examined supine with the stomach only part filled.

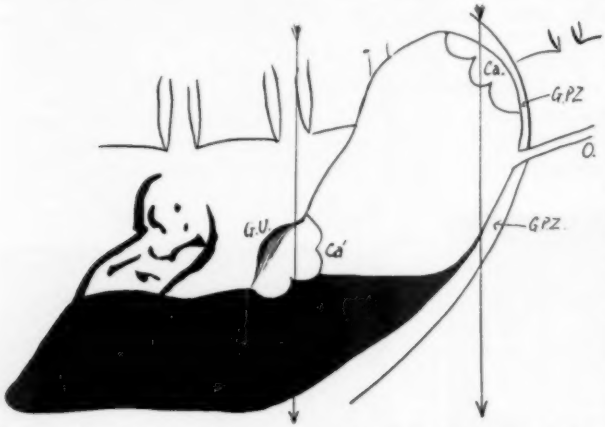

FIGURE XIIA. Lateral prone view of obtusely angled stomach. In a postero-anterior film the fundus growth, Ca, is concealed by the normal rugal pattern of the anterior wall. Lower down, the growth, Ca¹, or the ulcer, G.U., is concealed by the pool of barium. The arrows show direction of central ray in postero-anterior views.

Rotating the Patient.

Deformities of any part of the gastric wall are most easily revealed when the affected region lies in profile, on the edge of the gastric shadow. In order, therefore, to examine thoroughly the anterior and posterior walls, the patient must be rotated so that oblique and lateral views of the stomach are obtained. This rotation must be done with the patient supine, standing and prone.

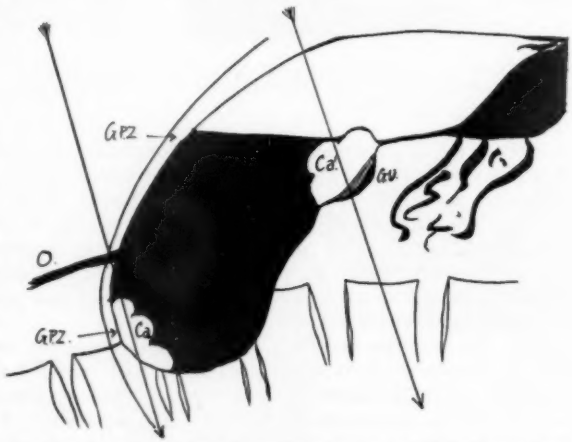

FIGURE XIIB. The lateral supine view. In an antero-posterior film the posterior wall lesions which were hidden in the prone view are now revealed. O = œsophagus; G.P.Z. = gastro-phrenic zone. Note downward tilt of central ray.

The Prone Position.

In many patients the prone position is the optimal position for the examination of the pylorus and duodenum. However, we are not concerned with these parts at present. But examples have been shown in which a

growth of the posterior wall of the upper end of the stomach has been obscured with the patient in this position, and revealed to the radiologist only when the patient was placed supine. Similar concealment may occur of an ulcer of the posterior wall at the cardiac end, penetrating the pancreas. Thus Figure XIA shows such a large ulcer in the supine view, but concealed in Figure XIB, the prone view. (I am indebted to Dr. Ron. Spedding for these.) The reason for this is clear in the diagram made by tracing lateral views of the stomach with the patient horizontal (Figure XII). In Figure XIIA the patient is prone and the pool of barium lies upon the anterior wall, washing upwards towards the cardiac end. It thus obscures the posterior wall in the postero-anterior skiagram, by imposing upon it the strongly marked pattern of the anterior wall, usually a complete opacity lower down and normal rugæ higher up. The posterior wall is lifted away by the layer of gas. But, with the patient in the supine position, these conditions are reversed; the normal anterior wall is lifted up by the gas and the posterior wall with its lesion is more freely bathed in barium, and its shadow, thus strongly marked, is imposed upon the skiagram.

As the patient is made to assume these various postures, not only does the barium pass to different regions of the stomach, but the shape of the stomach alters. I have heard these alterations described as distortions and advanced as a reason for neglecting to posture the patient. But they are not distortions. For each posture, each degree of tilt and each degree of rotation there is a normal outline, which will cease to appear as a distortion to the radiologist when he becomes familiar with the more extended and thorough examination of the stomach.

A suggested set of films for the cardiac end is here presented: (*a*) supine antero-posterior, (*b*) supine antero-posterior with downward tilt of central ray (Figure IX), (*c*) supine lateral (Figures X and XIIB), (*d*) upright lateral (Figure VIII). These views are intended to supplement, but not to replace, the postero-anterior upright and prone views at present favoured by radiologists.

The Clinician.

It is evidently not well known that a negative radiological report is utterly unreliable as disproof of gastric carcinoma (or of ulcer for that matter).

Certain duties devolve upon the clinician in his relationship with radiology.

1. When he refers his patient for radiological examination he must see to it that the possibilities of radiology have been exhausted and that his patient has received the utmost help from it. It may be necessary for the patient to pass to and fro between clinician and radiologist. The clinician must critically scrutinize the skiagrams and the details of the radiological examination, which have been made available to his patient. In this way the standard of radiological diagnosis in gastro-intestinal disease will be raised, as it has been raised in urology, neurosurgery and other specialities.

2. When the radiological report is "negative" and when the clinician is satisfied that the possibilities of radiology have been exhausted for the time being, he must either advise laparotomy or set a strict time limit—let us say six weeks—beyond which the indefinite continuation of medical treatment is unjustifiable. At the end of this six weeks the position must be reviewed, clinically and radiologically, and, if the diagnosis is still undecided, the choice must again be made, the clinician remembering that a negative radiological report is of little value and that delay is more dangerous than

laparotomy. Delay entails a heavy mortality and is used too frequently. If laparotomy were resorted to more frequently, lives would be saved by the discovery of lesions in a curable stage. To attain this end we would inevitably open the abdomen sometimes and find no lesion. But there should be no mortality from this.

During the period covered by this review one patient was seen with hypertrophic gastritis, diagnosed radiologically by Dr. B. P. Anderson Stuart. Laparotomy confirmed the absence of neoplasm. It was of a type first described by Konjetzny in 1938 and later discussed by Templeton and Schindler, often indistinguishable from carcinoma, not only clinically and radiologically, but also gastroscopically.

THE RADIOLOGIST.

For the radiologist there is only one rule, to carry out thoroughly a comprehensive and effective technique. At present he neglects the cardiac end. Of the nine diagnoses missed by the radiologist in this series, the original films are available for inspection in eight cases. In each of these eight there is an area near the cardiac end which suggests an organic lesion. In not one of the eight cases were those methods carried out which would have produced the correct diagnosis. Actually the radiologist's score in this series is worse than nine missed out of ten, because several of the nine were missed more than once.

The number of early lesions discovered must vary proportionately with the care and the time taken and with the thoroughness of the examination.

One source of error is the belief of some radiologists that a shadow deformity is of no consequence unless it is constant.

THE CLINICAL TEACHER.

In the past there have been teachers of medicine and surgery, and I believe that there are still some, who demonstrate patients with gastro-intestinal disease, but who make a point of disclaiming any knowledge of the radiology of these diseases. They ask for the radiologist's report and refuse to examine the proffered skiagrams. Such clinical teachers lose much as diagnosticians and they wield an undesirable influence upon students. To their example we owe much of the uncritical, ill-balanced evaluation of radiology which contributes so much to late diagnosis in carcinoma of the stomach. Such clinicians should give up the practice of gastro-enterology until they have served an apprenticeship in radiology. Otherwise they are like the carpenter who does not understand the use of a hammer.

SUMMARY.

The defective use of radiology by clinician and radiologist is prevalent. The causes and consequences are discussed in regard to carcinoma of the cardiac end of the stomach.

Present-day results are so poor that a new approach is suggested. A comprehensive set of films should be secured to show adequately all regions of the stomach, each region in two planes, and the gastro-enterologist, as well as the radiologist, should set his mind to the interpretation of these films. Such methods, applied in other branches of surgery and medicine, have led to an increase in diagnostic efficiency.

The failure of the cardiac end to balloon when the patient is supine, with the stomach as full as possible, is a sign of advanced carcinoma. Attention is drawn to this, not as a new sign, but as one that is frequently overlooked.

A technique has been suggested in the hope of securing the detection of growths when they are as large as a cherry, to supplement the present technique, which often overlooks them even when they are the size of a cricket ball. These supplementary views are like all other methods in medicine. They have their fallacies and their difficulties. But they should not be discarded on this account.

ACKNOWLEDGEMENT.

I am indebted to the radiologists of Saint Vincent's and Hornsby Hospitals for their cooperation, and not least to the technicians, whose interest and assistance have been invaluable.

ON THE DIAGNOSIS OF MALIGNANT TESTICULAR TUMOURS.[1]

By Norman Wyndham,
Sydney.

During the last three and a half years we have had the opportunity of studying thirty-five cases of testicular tumour. Such a wealth of clinical material has been made available by the generosity of colleagues, but even more so because, for half that time, many patients were evacuated to a large military base hospital where the writer was a member of the staff.

At first sight it might appear that tumours of the testicle were very common. This is not so, but they occur with sufficient frequency for it to behove everyone to be able to diagnose them with certainty. Although only fifty patients with testicular tumours were treated at the Royal Prince Alfred Hospital, Sydney, in thirty years, American authorities have found that these tumours form 0·58% of all malignant neoplasms in males. Dean (1935) places the incidence as high as 2·09%.

This paper deals in greatest detail with those features which are not usually considered characteristic. A heavy, rather insensitive, smoothly lobulated, testicular swelling occurring in a man between the ages of twenty and forty years is almost certain to be a seminoma or teratoma. If there are no signs of inflammation, if the Wassermann test gives no reaction and if the Aschheim-Zondek test gives a positive result, then the diagnosis is indeed easy. I want to point out that all these diagnostic criteria may lead to error at some time or another. Further, so urgent is orchidectomy in the case of teratomata that it is sheer folly to await the effect of irradiation in the hope that the condition is a seminoma.

Clinical Aspects.

Age of Patient and Length of History.

Teratomata of the testicle occur mostly in the third decade, while seminomata are found in men with greatest frequency between thirty and forty years of age. In this series there were few exceptions to this generalization.

It is not to be wondered at that many of the cases occurring amongst soldiers were reported early and, it is pleasing to note, were diagnosed correctly at an early stage. Communal life and the proximity of medical officers who commanded the trust and respect of the men made this possible. Five men reported within ten days of finding the swelling. Five others were seen a month or less after the tumour was first noticed. These early diagnoses with consequent prompt treatment should affect the ultimate prognosis. They are in contrast, for example, with those of Ferguson's (1934) series of which only 11% were free from secondary deposits. Nash and Leddy (1943) found secondaries in 47 out of 103 cases, Dean (1935) in 75% of cases on the patients' admission to hospital, and Bang *et alii* (1935) found that 13 out of 18 patients had metastases. In our series five had secondary deposits.

[1] Accepted for publication on November 5, 1943.

Relationship to Trauma.

Most, if not all, of these soldiers will be accepted as "war disabilities". The onus is on the Repatriation Commission to disprove liability. This is extremely difficult under any circumstance. In several instances the question has had to be considered.

1. G.E.B., aged twenty-one years, was struck on the right testicle with a cricket ball two months before being seen by us. On the night of the injury he had local pain but no testicular swelling. The latter did not appear for three days. A pre-operative diagnosis of tumour of the testicle was made and a teratoma growing from the position of the *rete testis* was found pushing into the body of the testicle, which was thinned out to form a capsule for the growth. Of course the tumour could not have been initiated and grown to this extent in three days.

2. S.C., aged twenty-four years, had a seminoma found by the surgeon during treatment for a traumatic rupture of the pelvis and urethra.

3. M.V.O'B., aged thirty-six years, was seen by his unit medical officer seven days after the soldier had slipped and struck the right testicle, which was situated in the inguinal canal. A swollen epididymis resulted, which was treated conservatively with no thought of malignancy. The swelling subsided, but recurred three weeks later. A teratoma was found at operation.

It is noted that in these three cases the attention of the patient was not directed to a swelling of the testicle because of an injury. It is just as obvious also that the warm seclusion of the abdominal cavity is no security against malignant change.

In a fourth case a tumour was found three years after a severe testicular injury. While some relationship may exist, it cannot be proven.

Relationship to Imperfect Descent of the Testicle.

The testicles were in their normal position in most cases. The following were exceptions:

1. F.J.W., aged thirty-three years, noticed a swelling in a testicle which had not assumed a scrotal position until the age of twelve and was then always smaller than the other.

2. T.D.McV., aged twenty-six years, had a teratoma in a normally placed left testicle, while the right one was situated high in the inguinal canal.

3. M.V.O'B., aged thirty-six years, was mentioned above as developing a teratoma in an injured undescended testicle.

4. T.A.B., aged forty-eight years, had a completely abdominal testicle if a testicle was present at all. He developed a teratoma in the other.

5. C.H.B., aged thirty-five years, a patient in the 3rd Royal Australian Air Force Hospital, had an abdominally situated testicle which became the site of a seminoma. Neither testicle was in the scrotum. For two years he had been investigated for attacks of left-sided abdominal colic which simulated Dietl's crises. At the end of this period he had a lump in the left groin and a tumour which appeared intermittently in the left hypochondrium. At operation the former mass proved to be a metastasis in lymph glands and the abdominal tumour a seminoma on a long narrow pedicle which attached it to the postero-lateral part of the pelvic brim and gave it a long range of movement so that it could assume a position in the pelvis or left hypochondrium.

6. G.G., aged thirty-two years, had the right testicle removed at the age of sixteen following injury. It was located in the inguinal canal. Sixteen years later his normally placed left testicle was found to contain a teratoma.

7. W.McE., aged thirty-three years, had a testicular swelling of eight weeks' duration before orchidectomy. At the age of nineteen years he had an operation for congenital right inguinal hernia. At that time his right testicle was always in the inguinal canal. No attempt was made to place it in the scrotum. His tumour was a chorionepithelioma.

8. I am indebted to Dr. Janet Elder, of Launceston, for the notes of another case operated on by Mr. Craig not included in this series. The patient was thirty-seven years old and had had a tumour in the lower part of the abdomen for two years with intermittent attacks of colicky pain, nausea and vomiting. Examination showed that neither testicle was in the scrotum and that there was a swelling of the lower part of the abdomen reaching to the navel. The Aschheim-Zondek test gave a negative result. At operation a very large mass was removed from the pelvis. A small testicle was adherent to one side of the lump. The tumour was a seminoma.

Four cases were associated with the abnormal development of the diseased testicle and three with imperfect descent of the apparently healthy organ. The significance of this is still disputed. MacKenzie and Ratner (1934), for example, deny any ætiological relationship. It is pointed out by Twombly (1944) that cryptorchidism occurred in 0·23% of American army recruits, while 11% of testicular tumours occur in cryptorchids. G. Gordon-Taylor's review of this aspect of the disease and the high incidence in his own cases indicate that some common factor must exist. I have already suggested (1943), in company with many observers, that a testis which cannot organize its own descent is inherently imperfect. It is understood, of course, that the deficiency may be in some extra-testicular controlling factor.

History Suggesting an Inflammatory Lesion.

The usual story is of a painless swelling and this was so in most of these cases. Testicular tumours are said to be insidious, fulminating, chronic or cryptic (Gordon-Taylor, 1938). It is stressed that another type, the pseudo-inflammatory, exists and presents difficulties and may respond to measures aimed at overcoming pyogenic lesions. This is amply illustrated by the following:[1]

1. S.C., aged thirty-seven years, had a slowly increasing swelling in the scrotum for two months, but had had pain for two days prior to reporting to a medical officer. On examination the swelling involved the epididymis more than the testicle. This was craggy and painful. Testicular sensation was normal. He was thought to have a tuberculous epididymitis. The Mantoux test gave a strong reaction. After further investigation the epididymis was removed and was found to be the seat of a tumour, a seminoma. Orchidectomy was performed immediately.

2. E.H.C., aged twenty-nine years, was seen two weeks after the onset of pain, tenderness and swelling in the right testicle. After a few days in bed, during which sulphathiazole was administered, the swelling subsided. This recurred a week afterwards. The excised testicle proved to contain a very malignant seminoma.

3. R.C.F., aged twenty-four years, entered hospital two weeks after the onset of pain and swelling in the left testicle. This came on one night after he had been swimming during the day. He was treated as suffering from acute epididymo-orchitis. The appearance of the testicle, epididymis and cord supported the diagnosis in every way. Testicular sensation was never lost. He had a teratoma. It has been obvious to us that loss of testicular sensation is by no means a constant feature.

4. G.G., aged thirty-two years, whose non-descended right testicle had been removed fourteen years earlier, developed spontaneous swelling in the left testicle. As this increased in size it became painful and the overlying skin became reddened. The swelling was tender, especially at its lower pole. The urine was normal, the Wassermann test produced no reaction, and the complement fixation test for Neisserian infection gave a negative result, as also did the Friedman test. There was no pyrexia, but the local signs improved following treatment with sulphadiazine. The lump was still there three months later, by which time the diagnosis was beyond doubt. Orchidectomy was performed. The tumour was a teratoma.

5. A.S., aged forty-nine years, noticed a painful lump in the left testicle seven months before admission to hospital. It had decreased in size on two occasions following the use of sulphonamides and local heat. His tumour was a seminoma.

Hydrocele.

In three instances a secondary hydrocele was detectable clinically. (These tumours rarely cause the accumulation of fluid in the *tunica vaginalis*.) One soldier had a hæmatocele as a result of needling. The danger of confusing hæmatocele with tumour, especially with teratomata of the hæmorrhagic or necrotic types, is obvious but not always appreciated. Blood can be aspirated from many such tumours to the confusion of the surgeon and the detriment of the patient. When justifiable doubt is present it would be better to expose these swellings surgically, to operate on a few

[1] The first three cases have been reported previously (Gordon-Taylor and Wyndham, 1947).

hæmatoceles unnecessary, rather than to miss the opportunity of removing a testicular tumour at the earliest possible moment.

Abdominal Tumour.

Four cases in this series presented as abdominal tumours. One soldier was admitted to hospital with a diagnosis of splenomegaly. On closer examination it was found that the tumour was a metastasis from a teratoma of the left testicle. The second instance was the one quoted above in which the abdomen contained a mobile, pedunculated testis, the site of a seminoma. The third patient had the classical appearance of the patient in the first case, a tumour of the left testicle and a mass in the left hypochondrium.

The fourth case is worthy of special recording because the patient's testicular tumour remained hidden for a long time. The affected testicle was smaller than the normally sized healthy one.

R.W.M., aged thirty-two years, was admitted to the Repatriation General Hospital, Concord, for investigation. He complained of aching in the loins, shortness of breath and swelling of both lower extremities. No cause was found for the dyspnœa, but, after much investigation, a diagnosis of thrombosis of the inferior *vena cava* or iliac veins was made, and subsequent improvement with heparin and the findings by venugram supported this. He was also found to have a strong Wassermann reaction due to an infection contracted five years previously, for which he had received treatment. Intensive antisyphilitic treatment was instituted. The possible connexion between his specific lesion and his thrombosis was considered. Following his anti-coagulant therapy he became an active man again.

Six months later he was readmitted to hospital with an abdominal tumour, which had the appearance of enlarged paraaortic glands. It was found that his right testicle was normal, but that his left testicle was half normal size and nodular. I decided to remove this and it was seen to contain two small seminomata, each about 1·0 centimetre in diameter.

Mr. Craig's patient quoted above presented as an abdominal tumour.

The necessity for examining the scrotum in all cases of abdominal tumour has been clearly shown by Osler (1907). It is not often emphasized how difficult it may be to feel the enlarged paraaortic glands even when one knows that the primary tumour exists and feels certain, from the general condition of the patient, that abdominal metastases are present. Tenderness with reflex muscle guarding of the abdominal wall may render the tumour masses impalpable.

Lung Lesions.

Teratomata frequently give rise to secondary deposits in the lung. Even though this is well known, diagnostic confusion may occur. The condition is often considered to be pneumonia until full clinical examination reveals the primary tumour or, more often, X-ray investigation of the lungs shows the rounded, secondary deposits. In the early stages of the development of these metastases the diagnosis may be difficult, even though the true nature of the lesion be suspected.

In one of our cases, that of a young man of twenty-six years, the condition was stated to be pneumonia. The clinical appearance supported this, and after he had been ill for five days the radiological appearance of the chest was that of an inflammatory lesion. Two weeks later the radiologist reported: "There is a consolidation at the right base with some fluid extending upwards in the axillary line". We knew that he had a tumour of the testicle, which had been first noticed by the patient nine months before. It was considered, in spite of the above findings, that the condition was one of pulmonary metastasis. Although the man was gravely ill, the testicle was removed under local anæsthesia. The tumour was a seminoma. Irradiation of the chest resulted in the disappearance of metastases. The man is alive and well two and a half years later.

Gynæcomastia.

Two men, one with a seminoma and one with teratoma, had enlarged mammary glands. Twombly (1944) considers that this phenomenon is of bad omen. Certainly both of these patients of ours died.

Clinical Appearance of the Tumour.

It is obvious that consistency in size of these tumours is not to be expected. As already indicated, one seminoma occurred in a testis smaller than its normal companion. They are usually smoothly lobulated, but sometimes, especially in the case of teratomata, cystic or cartilaginous areas may be found. The former may be closely simulated by areas of necrosis in a seminoma or hæmorrhagic adenocarcinoma and occasionally residual testicular tissue pushed to one side may feel hard in comparison with a soft tumour. Clinically, it is often difficult to tell whether the tumour is a seminoma or teratoma. This has an important bearing on treatment. While radiotherapy is a valuable aid in the treatment of seminomata, it is useless in teratomata and valuable time may be lost in proving the insensitivity of a testicular tumour to irradiation. All testicular neoplasms must be removed.

Testicular tumours vary in consistency from hard to soft. They are rarely as uniform as the swelling of the syphilitic testicle. Nor do they always feel as heavy. Frequently careful palpation will reveal a place where testicular sensation remains. It must be admitted that an orchidectomy was performed in the case of a lad of twenty-four years of age because of a moderate-sized testicular tumour associated with a positive response to the Aschheim-Zondek test. The tumour was a gumma.

Many tumours commence in the region of the *rete testis*. It may be hard to tell whether the swelling is primarily testicular or epididymal if the direction of spread is toward the epididymis. Several of such tumours have been reported in the literature as tumours of the epididymis, a very rare growth indeed.

It has been already shown how the history of these swellings may suggest inflammatory conditions. In these cases the clinical appearance would support such an opinion and I can suggest no quick, sure way of deciding this important point. Such lesions may, with justification, be treated primarily as inflammatory, but every one should be followed to a successful conclusion, else will the favourable opportunity for cure be lost.

HORMONAL INVESTIGATIONS.

This is a paper on diagnosis, so that it should be stated clearly that reliance cannot be placed on the infallibility of urinary hormonal tests in the diagnosis of these tumours. The tests are of great interest and of undoubted importance in the study and understanding of such growths, but it has been made clear during the management of these cases that testicular tumours may exist in the presence of a negative response to the Aschheim-Zondek test and that erroneous conclusions may be drawn as to the histology of such tumours from studies of the urinary hormonal secretion alone.

It might be assumed from a study of this part of the paper that the type of tumour, judged by histological examination, can be stated with confidence in every case. In a general way, this is so, but more exact opinions regarding degree of malignancy and histogenesis cannot always be given with certainty. Even though one might refrain from entering into this controversy in this paper, some general conclusions can be stated as to the hormonal findings in some of our cases.

Current Opinion.

The hormonal relationship of testicular tumours has not been determined completely beyond room for argument, although much work has been done since the original observations of Zondek (1930). Most testicular tumours

are associated with the excretion in the urine of a hormone almost, if not entirely, identical with the anterior pituitary-like hormone of pregnancy urine (Fluhmann and Hoffman, 1936). Twombly (1944) states that the chorionic type of hormone is more typical of embryonal adenocarcinoma and chorionepithelioma, while seminomata are associated with the production of a follicle-stimulating hormone like that found in castrate's urine. With the abundance of production of these hormones there is a diminution in the amount of androgenic hormone in the urine, especially in the case of seminomata. On the other hand, when the hormone secreted is a chorionic gonadotropin, large amounts of œstrogens are produced simultaneously.

Francis (1945), in a review of the literature, quotes the view of several independent authorities who believe that teratomata themselves produce a luteinizing hormone while seminomata produce none. In the presence of either tumour the compression of the surrounding testicular tissue stimulates the pituitary to produce a follicularizing hormone. Ferguson (1935) and other American observers grade the tumours according to the number of mouse-units of hormone per litre of urine. Patients with chorionepithelioma have the highest concentration and then, in descending order, adenocarcinoma, seminoma and adult teratoma. This confidence is not universal amongst pathologists and it is, in part, the purpose of this paper to state that, in this small series, hormonal investigations could not be relied upon to give a sure indication of the histopathology of the tumour.

Results in this Series.

Complete hormonal investigation was not possible in every case because of the conditions under which some patients received their early treatment. In others, qualitative and not quantitative estimations were made. This consisted in many cases of the recording of the response to the Aschheim-Zondek test. Opinion as to the presence of *corpora lutea* or *corpora atretica* was not always given because at first we did not realize the significance of this. In some cases the Friedman test was used.

Seminomata.—It is a fairly common finding abroad for seminomata to be associated with inconsistent results. Our results pre-operatively were as follows:

Follicularizing but no luetinizing hormone present in the urine ..	6
Neither hormone present	4
Test not performed	6
Total cases	16

Of these patients two have died. In neither case was a urinary hormonal test performed before operation. In one of these such a test was performed when metastases later appeared. A positive result for follicularizing hormone was obtained.

Three others gave a positive response to tests three weeks or more after removal of a seminoma followed by irradiation. One of these has had several metastases treated by irradiation during the last two years. The other two are alive and well more than two years later. Most of the remainder have given negative results to tests at intervals since operation. I cannot see why the response to the Aschheim-Zondek test becomes negative. Orchidectomy cannot remedy the relatively eunuchoidal state.

Adult Teratomata.—For our present purpose the name adult teratoma is given to a tumour in which attempts are made to form recognizable tissues from more than one germ layer. We shall not discuss the virtues or errors of this. Their pre-operative qualitative hormonal results were as follows:

Aschheim-Zondek test, positive response	4
Aschheim-Zondek test, negative response	3
Aschheim-Zondek test not made	3
Total cases	10

Out of ten patients with this histological type, two have died. No test was performed in three instances. In two instances in which a positive result was obtained, the presence of luteinizing hormone was detected.

Amongst the results obtained during the routine "follow-up" two results are of interest. The appearance of these hormones in the urine at a later date is usually taken to signify the development of metastases. In these two instances the response to the Aschheim-Zondek test has become positive. In one case the hormone is follicularizing; in the other, *corpora lutea* were formed in both of the test animals' ovaries. Both men are well, although the above results were obtained one and a half and two and a half years ago respectively.

Carcinoma.—Exception may be taken to the use of the term carcinoma. By this is meant a unicellular malignant tumour not resembling seminoma. Whether some of them are carcinomata of teratogenous origin cannot be proven in many cases. Teratomata of different types are almost always found if one searches diligently to contain more than one type of cell. Epithelial growths, for example, are associated with more connective tissue neoplasia than is typical, say, of adenocarcinoma of other organs. A unicellular malignant testicular tumour can, therefore, be called simply a carcinoma. In the literature we find that such tumours are associated with a high hormonal excretion. In this series three tumours presented this appearance. In one case no test was performed. In the second a moderately high concentration of follicularizing hormone was present in the urine one month after, but not before, operation, but in the third instance the concentration in the urine was only 1,500 mouse units per litre of follicle-stimulating hormone. There was a twenty-four hour excretion of 18·8 milligrammes of ketosteroids. Moreover, these estimations were repeated with similar results when there were large metastatic deposits throughout the body.

The first patient died within twelve months. In the second instance the presence of a reaction to the Aschheim-Zondek test after treatment and a very malignant-looking tumour on section made the prognosis bad. It is two and a half years since treatment was concluded, at which time the officer was repatriated to England. His history has not been obtained so far. The third patient died within two years.

Thus in two instances of very malignant growths, hormonal investigations gave fallacious information regarding degree of malignancy.

Adenocarcinoma.—Two highly malignant hæmorrhagic adenocarcinomata were encountered. In neither case were hormonal investigations performed.

Chorionepithelioma.—Three specimens in the category of chorion-epithelioma occurred in the series. High concentrations of follicularizing and luteinizing hormone were present in the urine in all cases.

SUMMARY.

The possible variations of the history and clinical appearance of testicular tumours are described.

The association with trauma, imperfect development, pseudo-inflammatory onset and distant metastases is outlined.

The results of hormonal investigations are given in a limited number of cases and the fallibility of these tests as diagnostic procedures is emphasized.

ACKNOWLEDGEMENTS.

Much of this work could not have been done but for the assistance of Major G. V. Rudd, formerly officer in charge of the department of pathology, 113 (Concord) Military Hospital, and of Dr. E. M. Day, department of biochemistry, Royal Prince Alfred Hospital, Sydney. Valuable help in connexion with hormonal assays was rendered by Mr. Whitton, of the Gordon Craig Urological Research Laboratory, the University of Sydney.

BIBLIOGRAPHY.

F. Bang, C. Hamburger and J. Nielsen: "*Essai de classification des tumeurs du testicule*", *Bulletin de l'association pour l'étude du cancer*, Volume xxiv, June 5, 1935, page 418.

A. L. Dean: "Teratoid Tumours of the Testis", *The Journal of the American Medical Association*, Volume cv, 1935, page 1965.

R. S. Ferguson: "Studies in the Diagnosis and Treatment of Teratoma Testis", *American Journal of Roentgenology*, Volume xxi, 1934, page 356.

R. S. Francis: "The Status of Hormonal Bioassay in Malignant Disease of the Testicle", *The British Journal of Surgery*, Volume xxxiii, 1945, page 173.

C. F. Fluhmann and P. E. Hoffman: "Gonad-Stimulating Hormone in the Urine of Men with Tumor of the Testis", *The Journal of Urology*, Volume xxxiv, 1935, page 55.

G. Gordon-Taylor and A. S. Till: "Malignant Disease of the Testicle, with Special Reference to Neoplasms of the Undescended Organ", *The British Journal of Urology*, Volume x, 1938, page 1.

G. Gordon-Taylor and N. R. Wyndham: "On Malignant Tumours of the Testicle", *The British Journal of Surgery*, Volume xxxv, July, 1947, page 6.

D. W. McKenzie and M. Ratner: "Metastases from Tumors of the Testis", *The Journal of Urology*, Volume xli, 1939, page 592.

L. A. Nash and E. T. Leddy: "Seminoma of the Testis from the Standpoint of Roentgen Treatment", *American Journal of Roentgenology*, Volume l, 1943, page 162.

G. H. Twombly: "The Relationship of Hormones to Testicular Tumors", *Surgery*, Volume xvi, 1944, page 181.

N. R. Wyndham: "A Morphological Study of Testicular Descent", *Journal of Anatomy*, Volume lxxvii, 1943, page 2.

B. Zondek: "*Versuch einer biologischen (hormonalen) Diagnostik beim malignen Hodentumor*", *Der Chirurg*, Volume ii, 1930, page 1072.

OBSERVATIONS ON THE COURSE OF RECOVERY AND LATE END RESULTS IN A SERIES OF CASES OF PERIPHERAL NERVE SUTURE.[1]

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I. INTRODUCTION.

THE purpose of this paper is to detail the course of regeneration and the extent and quality of the final recovery following the repair of peripheral nerves at varying intervals after injury. The observations are from the personal records of 55 patients who were treated at the 115th Australian Military Hospital over the period 1941 to 1946; the records of three patients are not sufficiently complete to warrant my reporting them. Seven additional examples of nerve suture provided by six patients (a boy kindly referred to me from the Children's Hospital, Melbourne, and five servicemen) have been included in this paper, though they are from a new series collected subsequent to the report on "Observations on the Treatment of Traumatic Injuries of Peripheral Nerves" (Sunderland, 1947) in which only 55 cases of suture were listed. A follow-up of patients on their discharge has been possible through the cooperation and kind offices of the Repatriation Department. In this way an unbroken record of the sequence of events following repair has been obtained which in most cases has extended over four years.

Difficulty in maintaining case records must occur when the wounded soldier is being transferred from hospital to hospital, which brings him under the care of a succession of medical officers, none of whom is able to make prolonged observations. Most of the patients in the present series reached Melbourne within a few weeks or months of their injury and from that time onwards remained under the care of the author. This considerably reduced the difficulties in maintaining records introduced by the transferring of patients from clinic to clinic. In addition, it has often been possible to review cases of suture of the same nerve on the same day, so that it has been possible to compare and accurately grade the end results. Though the series is small, it is felt that there is sufficient detail to make the observations of importance.

When reporting on their case records of large series of peripheral nerve sutures from World War II, recent writers have attempted only a general analysis of the material with the principal object of determining, on the basis of the end result, the optimum time for repair. One difficulty about much of this material is that the records were provided from a number of sources and represent the combined efforts of a number of observers—for example, 85 surgeons contributed the 5,000 cases reported by Spurling and Woodhall (1946). The statistical analysis of such material, where the personal factor is high and significant, is not easy and, as Spurling and Woodhall point out, it remains for personal series to provide details. It is only when these are available that conclusions relating to many events in the reparative process will become decisive. The only series reported in detail to date is that by Stopford (1920), who confined his attention to the motor recovery following secondary suture.

[1] Accepted for publication on November 12, 1948.

II. MATERIAL, ASSOCIATED PHENOMENA AND TREATMENT.

The observations were made on 10 cases of suture of the radial nerve, 14 of the median, 26 of the ulnar and nine of the sciatic and its popliteal divisions. The case reports contain only a brief reference to events occurring in the regenerative process and to the end result; to conserve space the essential details are given in Tables I to XVIII.

In order to avoid repetition and unnecessary discourse certain features which are common to several sections of the paper will now be discussed.

Combined Lesions.

In combined lesions only the nerve requiring suture has been reported. All reference to accompanying lesions recovering spontaneously has been omitted.

Infection and Scarring.

An attempt has been made in each case to assess the degree of infection and local scarring originally present about the nerve in order to evaluate the influence of these factors on repair and the course of recovery. This is difficult and only the simplest classification into "significant" and "insignificant" has been attempted. The degree of infection has been assessed on the general symptoms, wound culture, the presence or absence of osteomyelitis, the period during which the wound discharged, the time taken for the wound to heal, and the extent of residual scarring. The degree of scarring has been estimated on the extent of soft tissue injury, the area and character of the residual scar and whether this was adherent, free, depressed or otherwise.

Electrical Stimulation.

The term "stimulation" appearing in the case records refers to the direct electrical stimulation of the exposed nerve above and below the site of damage both before and after mobilization.

Suture.

Unless otherwise stated, the following suture technique was adopted in each case. The nerve ends were suitably prepared (see Section X) and were united with interrupted radially placed sheath sutures only, care being taken to avoid axial rotation. The number of sutures varied from five to twelve, depending on the size of the nerve, the proximity of the suture line to a joint, and the tension obtaining. In only one case was the suture line encased in material. Extension of the forearm and leg following flexion to permit union was commenced approximately three to five (for the arm) and four to six (for the leg) weeks after repair; full extension was gradually achieved over the following three weeks. The suture materials used are listed in Tables I, IV, VIII and XIV.

Treatment.

Patients received massage, heat treatment, remedial and reeducational exercises and, in the later stages of hospitalization, occupational therapy. Treatment was intensive while patients were in hospital (six to nine months following the injury); on their discharge physiotherapy for those in city centres was continued, if necessary, two or three times weekly for a further two years. Once the patient is active and employed, however, physiotherapy is an unnecessary luxury; the average patient should, by this time, have acquired sufficient knowledge of the elementary principles underlying such

treatment to become responsible for the procedures which exercise paresed muscles and prevent periarticular adhesions. Galvanic stimulation was not employed as a routine; it was used consistently in the treatment of only one patient (Case 40, radial repair).

Splinting.—Splinting was applied with due regard to the maintenance of joint movement and the prevention of adhesions.

Paralysed muscles are easily overstretched and permanently lengthened, which reduces their efficiency when voluntary contraction returns. In some regions such overstretching is prevented by other muscles which by their action provide periods of rest for the denervated muscle. Thus in ulnar nerve lesions the involved *flexor carpi ulnaris* is protected against overstretching by two agencies—flexion of the wrist by gravity and the action of the *flexor carpi radialis*. Where no such natural resting mechanism is available, failure to provide artificial relaxation in the form of suitable splinting leads to the overstretching of muscles by gravity and by the action of unopposed antagonists, while the formation of irreducible contractures is encouraged.

Radial Nerve.—In all cases the forearms were splinted in light plaster moulds with mild hyperextension of the wrist, extension and partial radial abduction of the thumb and extension of the fingers at the metacarpo-phalangeal joints. I believe in the value of such support for the thenar and metacarpo-phalangeal joints provided that supervised movements are carried out daily. In no case did joint stiffness develop when these precautions were taken, but only followed prolonged, unrestricted and uncontrolled immobilization.

When the power of wrist extension had reached useful proportions and voluntary contraction had appeared in the digital and thenar muscles, the mould was discarded and a wrist band substituted which maintained extension of the metacarpo-phalangeal joints by means of rubber strips passing to digital and thenar cuffs. This permitted free and useful digital movements while ensuring relaxation of the involved muscles during rest. The digits were supported thus until the power of extension of the fingers and of thenar radial abduction was strong enough to warrant their release.

Median Nerve.—The only splint employed was a thenar cuff linked to a wrist strap by a rubber band which maintained the thumb in palmar abduction (based on the appliance of Froment and Wehrlin, 1915). Whether this was of value in aiding motor recovery is questionable, but several patients claimed that they found it helpful.

Ulnar Nerve.—The development of irreducible flexor contractures of the ring and little fingers was prevented by appropriate splinting. Where there was soft tissue damage in the forearm the splinting was directed to counteracting any flexor contracture which might develop with scarring and healing rather than to relaxing the intrinsic muscles.

Sciatic Nerve.—Elevation of the foot was maintained in bed by a light cast, while during the day a toe-raising spring to aid dorsiflexion was the standard mechanical aid for lateral popliteal damage. It should be noted, however, that many of the splints designed for this purpose do not always rest the paralysed anterior tibial group. Thus, when walking, such aids do not prevent the leg being carried forcibly backwards on the foot; consequently with every step the anterior tibial muscles are stretched. This may partly account for the poor recovery observed in this group.

These points are mentioned solely to emphasize the importance of physiotherapy and of preventing the overstretching of muscles and the formation of periarticular and articular changes which adversely restrict joint movement.

III. Evaluation of the End Result.

The extent and quality of final motor recovery have been set out in more detail in the case reports and tables than is covered by the classification recommended in the Medical Research Council War Memorandum No. 7. The abbreviated form of assessment set out in the memorandum is most useful when considering large series in broad outline, but it is quite inadequate when methods of treatment and the many "variables" affecting recovery after suture are under review. For the latter purpose it is necessary to make the most detailed end-result assessments. Assessments in the past have been too vague to be of value in this regard.

Motor Recovery.

Palpable contraction of the muscle, or movement which was undoubtedly attributable to its action alone, was the criterion adopted for detecting returning function. Due regard was paid to the possibility of transmitted contraction and trick movements (Wood Jones, 1919; Sunderland, 1944). In order to detect the earliest signs of recovery, patients were examined at weekly intervals until all muscles were contracting; from then onwards the examinations were conducted at monthly, then three-monthly and finally six-monthly intervals. Where weekly examinations were not possible and the first appearance of recovery could not therefore be given accurately to a specific week, the last date when the muscle was known to be still paralysed and the date when recovery was first detected have been given.

The end result for each movement has been expressed in terms of its range and power compared with those of the corresponding movement on the opposite side. The range was measured with a protractor and power with spring balances. To record the power the part was voluntarily carried through the full range of movement possible and was maintained in that position against tension applied through a cuff encircling the part. The power was that required to initiate movement against voluntary resistance. The process was then repeated on the opposite side. In the tables the range and power are expressed as percentages of the normal. In arriving at values for the range and power every care was taken to eliminate the compensatory action of uninvolved muscles, but this was difficult in some cases. For example, when testing flexion of the little finger at the metacarpo-phalangeal joint with the phalanges fully extended (ulnar intrinsic musculature) it was difficult to exclude the *flexor sublimis* (and the *flexor profundus* when this muscle was supplied entirely from the median nerve or when the ulnar lesion was situated below the origin of the branches to the muscle). Immediately flexion occurred at the interphalangeal joints during the test it was accepted that the long flexor was participating—the range and power were then recorded.

Where it was not possible to dissociate the action of muscles normally combining with the involved muscle in the production of movements (for example, the *flexor carpi radialis* and the *flexor carpi ulnaris* in producing wrist flexion) no attempt has been made to assess function in terms of range and power. The state of contraction has accordingly been described in such cases as strong, weak or feeble, depending on (*a*) the amount of residual wasting, (*b*) the prominence of the muscle and its tendon on full contraction as ascertained by inspection and palpation, (*c*) the power and efficiency of the movement which it was assisting to produce, and (*d*) the extent to which the compensatory action of other muscles was required to assist the movement—for example, the *flexor pollicis longus* compensating for the *adductor pollicis*.

In the case of the ulnar nerve additional information relating to recovery in the hypothenar muscles was obtained from observations on: (i) The amount of hypothenar elevation occurring on opposition of the thumb and little finger (Sunderland, 1944). This provided a measure of the recovery, particularly in the opponens. (ii) The absence of a residual griffe deformity of the ring and little fingers or, where present, the extent to which it was developed.

In the present series no tests were made to ascertain the capacity of muscles, assessed as having fully recovered, to stand up to prolonged effort. Had such tests been made, the indications are that they would have revealed that the involved muscles would have tired more readily than the uninvolved; this was elicited from careful questioning of the patients.

Wasting.

The residual wasting has been expressed in terms of the difference between the circumference of (*a*) the forearms, 7·5 centimetres below the medial epicondyle of the humerus, (*b*) the hands, at the level of the fully radially abducted thumb, and (*c*) the legs, 20 centimetres below the upper border of the patella with the limb relaxed in the fully extended position.

Sensation.

References in the case records to disturbances of sensation in the cutaneous field and to sensory recovery relate specifically to the autonomous zone served by the severed nerve and not to the original area of defective sensation. The latter usually undergoes early shrinkage, but I regard this as being due not to regeneration but to functional readjustments occurring in cutaneous zones which are innervated by neighbouring nerves as well as by the injured nerve and whose functional efficiency has been temporarily depressed by the elimination, from injury, of one of the sources of nerve fibres.

Pinprick (hatpin), light touch (camel hair), two-point discrimination (compass points) and temperature sense (copper disks and test tubes), and joint sensation were all tested. The patients varied so widely as witnesses and the sensation elicited by each type of stimulus presented such variable, temporal, zonal and individual peculiarities that it was difficult to establish standard grades of sensory recovery that would encompass all features. The following abbreviated terminology, however, has been employed to denote the quality of each modality.

Pinprick:

P.0.—Cutaneous field anæsthetic.

P.1.—Awareness of a change of state; usually interpreted as contact and probably due to transmission to deep tissues. The patient is unable to distinguish between the application of the head and point of a pin. The sensation may or may not be localized.

P.2.—The patient can distinguish between the application of the head and point of a pin. The latter stimulus gives rise to (i) a dullish prick or (ii) an unpleasant sensation, with considerable radiation and false reference.

P.3.—Sharp tingling or stinging sensation with some radiation and false reference. Localization, other than to the hand or digit and the leg or foot, absent.

P.4.—A sensation of sharpness with or without some tingling or stinging and with no or very little radiation. Localization correct to within 2·0 centimetres.

P.5.—Normal sensation of sharpness, which is accurately localized.

Light Touch:

T.0.—No appreciation of light touch.

T.1.—Awareness of a change of state on the application of the hair.

T.2.—Light touch gives rise to a radiating tingling sensation and the point of stimulation cannot be localized.

T.3.—Light touch just perceptible as such with no localization other than, in the case of the hand, to the palmar field, back of the hand or digit, and, in the case of the lower limb, to the leg or foot.

T.4.—Light touch appreciated as such, but with diminished acuity. Localization correct to within 2·0 centimetres.

T.5.—Normal sensation elicited by light touch.

Two-Point Discrimination:

D.0.—No two-point discrimination.

D.1.—Some two-point discrimination, which is, however, still defective.

D.2.—Two-point discrimination within normal limits.

Temperature:

T°0.—No temperature sensibility.

T°1.—Insensitive to cold and heat except at high thresholds, when the sensation elicited is interpreted as painful.

T°2.—Temperatures below 15° C. and above 60° C. are correctly interpreted as cold and hot respectively. Inside this temperature range the application of the disk or tube elicits a sensation of touch or pressure.

T°3.—Temperatures below 20° C. and above 35° C. are correctly interpreted as cold and hot respectively. Inside this temperature range the application of the disk or tube elicits a sensation of touch or pressure.

T°4.—Normal temperature sensibility.

IV. CASE RECORDS.

Unless otherwise stated, the number of weeks given in the progress reports represents in each case the period of time as calculated from the date of repair. This will avoid repetition of the phrase "after the repair".

1. *Radial Nerve Suture: Case Records.*

CASE 12.—On August 28, 1941, J.S. sustained a perforating gunshot wound of the left forearm, which resulted in a comminuted fracture of the upper third of the radius and complete loss of function in the field of the posterior interosseous nerve. The entry scar was circular, 1·0 centimetre in diameter, on the ulnar border of the forearm, 7·0 centimetres below the medial epicondyle. The exit scar was circular, 1·3 centimetres in diameter, in the mid-line of the dorsum of the forearm, 9·0 centimetres below the lateral epicondyle. The wound was infected and the fracture failed to unite.

The nerve was explored 273 days after the injury. Shortly after emerging from the supinator it ended in a firm bulb, about the size of a pea, from which a short stump emerged which sprayed into a series of branches. A spur projecting from the upper bone fragment was in close proximity to the bulb and the arrangement suggested that this spur might have been responsible for the nerve lesion. The involved segment was excised and the nerve ends trimmed; care was taken to preserve some distal stump for suture since individual branches were too fine for this purpose. It was realized at the time that more extensive resection, both proximally and distally, was desirable, but this would have introduced an irreducible gap. Even after full flexion of the elbow union could only be effected under tension.

Progress Report.—On the day following the operation the patient, contrary to instructions, was allowed to extend his forearm; this probably resulted in a separation at the suture line. At 136 weeks the *extensor carpi ulnaris* and the *extensor digitorum communis* were contracting feebly. Appropriate tendon transplantations were executed five weeks later. When the patient was last examined at 287 weeks there had been no further improvement in nerve function.

CASE 40.—On November 19, 1941, K.H.McN. sustained a perforating machine-gun bullet wound of the right cubital fossa which resulted in considerable soft tissue damage and complete loss of function in the field of the radial nerve below the supply to the brachio-radialis. At the point of entry there was a circular scar in the cubital fossa immediately lateral to the margin of the biceps. At the point of exit there was a ragged scar extending upwards for 6·5 centimetres from the lateral epicondyle. The wound was infected and there was considerable residual scarring. Transport of the patient from the Middle East delayed exploration of the nerve, which was not performed until 313 days after the injury. A bulb was palpable in the supracondylar region before operation and the lesion was still complete. The nerve had been completely severed and the separated nerve ends were embedded in scar tissue with a large proximal

neuroma; these were freed, prepared for union and sutured without tension with the forearm fully flexed. The posterior cutaneous nerve of the forearm was not seen at the operation, though sensation was grossly defective in the field of this nerve.

Progress Report. — Contraction was first observed in the *extensor carpi radialis longus* at twenty weeks; the remaining muscles were reinnervated in anatomical order until all were contracting twenty weeks later. The extent and quality of the motor recovery when the patient was last examined at 330 weeks are given in Table II.

Before exploration there were 3·5 centimetres of forearm wasting; at the last examination this had been reduced to 7·0 millimetres. The area of sensory defect over the dorsum of the forearm and hand was unchanged, though within the area sensation had improved. The patient could distinguish between the application of the head and point of the pin in the forearm area, the latter giving a localized sensation of sharpness; light touch was felt and correctly localized. In the superficial radial field the patient was unable to distinguish between the application of the head and point of the pin. Both were identified as contact; the site of the stimulus was well localized. Light touch was appreciated only as a change of state.

CASE 166.—On October 26, 1942, J.C. sustained a penetrating shrapnel wound of the left forearm, which resulted in complete loss of function in the field of the posterior interosseous nerve. The entry wound was linear, 3·0 centimetres in length, and crossed the dorsum of the forearm 7·0 centimetres below the lateral epicondyle; it did not become septic. In the absence of spontaneous recovery the nerve was explored 207 days after the injury. The proximal stump ended blindly in scar tissue between the two sheets of the supinator; it was freed. The distal stump was located 2·0 centimetres further distally; it was 3·0 millimetres long and forked into two divisions. Neither neuroma nor glioma was present. There was little surrounding scar tissue. Stimu-

TABLE I.

Radial Nerve: Information Relating to the Injury and Conditions of Repair.

The cases have been grouped according to the causative injury and the duration of the interval elapsing between injury and repair.

Cause and Nature of Causative Injury.	Age.	Level of Suture in Centimetres.	Interval in Days between Injury and Repair.	Infection.	Scar.	Length of Nerve Destroyed.[1]	Tension (with the Limb Postured).[2]	Treatment of Nerve Ends.	Suture Material.
Laceration:									
282. I.G.C.	34	12·5 above L.H.E.[3]	Two hours	Nil.	Nil.	Negligible.	No.	Adequate.	
180. W.W.	35	4·0 above L.H.E.	38	Nil.	S.	Small.	No.	Adequate.	
225. H.J.P.	—	Supracondylar region.	Immediate resuture: 28 weeks	Nil.	Nil.	Intermediate.	No.	Adequate.	
Gunshot wound:									
248. W.R.L.	26	Axillary outlet.	154	I.	S.	Considerable.	Yes.	Inadequate.	
166. J.C.	41	In supinator.	207	Nil.	Nil.	Intermediate.	No.	Adequate.	
332. O.J.P.L.	22	Just below the epicondyle.	235	Nil.	Nil.	Unknown.	Unknown.	Unknown.	Black silk.
40. K.H.McN.	28	5·0 above L.H.E.	313	I.	S.	Intermediate.	No.	Adequate.	Tantalum.
Gunshot wound plus bone injury:									
221. W.J.W.	33	Mid upper arm.	267	I.	S.	Considerable.	Yes.	Adequate.	Deknatal.
12. J.S.	32	Lower margin of supinator.	273	I.	Nil.	Intermediate.	Yes.	Inadequate.	Black silk.
243. J.H.B.	22	Just above L.H.E.	316	I.	S.	Considerable.	No.	Inadequate.	Black silk.

[1] Length of nerve destroyed: 1 to 4 mm. = negligible; 5 to 10 mm. = small; 11 to 30 mm. = intermediate; 30 + mm. = considerable. [2] Tension after mobilization and posturing of the limb. [3] L.H.E. = Lateral epicondyle of the humerus.

lation failed to elicit a response. Trimming away a few millimetres of the proximal stump revealed intraneural conditions suitable for repair. The face of the short distal stump only was shaved in order to avoid undue further shortening, which would have encroached on the branches and thereby increased the hazards of repair. Union was effected without tension with full elbow flexion.

Progress Report.—Contraction of the *extensor carpi ulnaris* and *extensor digitorum communis* commenced at nine weeks; 16 weeks later all muscles were contracting. The extent and quality of the recovery at the last examination, at 240 weeks, when the condition was stationary, are given in Table II. At the time of suture there were 18 millimetres of forearm wasting; at the last examination there was no wasting.

CASE 180.—On March 10, 1943, W.W. sustained a bayonet wound which completely interrupted conduction in the radial nerve. The bayonet entered the volar aspect of the right forearm 10 centimetres below the medial humeral epicondyle and emerged from the postero-lateral aspect of the arm 7·5 centimetres above the lateral epicondyle. The wound was not infected, but the long flexor mass was lacerated with resultant moderate scarring. Exploration 38 days later revealed that the nerve had been severed in the supracondylar furrow above the branches to the brachio-radialis; it was sutured. The posterior cutaneous nerve of the forearm was independently severed, but was not repaired. No further details were available.

Progress Report.—Recovery commenced in the *extensor carpi radialis longus* at 20 weeks and proceeded uninterruptedly until all muscles were contracting a further 22 weeks later. Motor function had recovered to such an extent at 52 weeks that the patient was discharged from hospital; the extent and quality of the recovery at this time are given in Table II. The patient was not seen again, though further improvement was expected. There had been no sensory recovery.

CASE 221.—On August 19, 1943, W.J.W. sustained a perforating shrapnel wound of the right arm with a comminuted fracture of the mid-third of the shaft of the humerus. The entry scar was circular and depressed, at the anterior border of the deltoid opposite the lower margin of the *pectoralis major*. The exit scar was curved, 11·5 centimetres long, and extended downwards from the axilla along the postero-medial aspect of the arm. Local scarring was considerable. There was a complete lesion of the radial nerve below the branches to the triceps. Persistent infection delayed exploration of the nerve until 267 days after the injury. When traced distally from the axilla, the nerve was found to end in a bulb at the entrance to the spiral groove; the lower end was not found. The nerve was then exposed in the supracondylar region and traced upwards until it ended in dense scar tissue in the groove. The distal segment was mobilized and transferred to the medial side of the arm between the biceps and brachialis muscles. The upper and lower ends were then suitably prepared and sutured under light tension on the medial side of the arm.

Progress Report.—There was no evidence of any regeneration 50 weeks after suture and appropriate tendon transplantations were performed. There were no signs of regeneration at 214 weeks.

CASE 225.—H.J.P. In January, 1941, a neurofibroma of the supracondylar section of the radial nerve, immediately above the origin of the branches to the brachio-radialis, was excised. Details relating to the primary suture were not provided. In the absence of recovery 28 weeks later the nerve was explored. At the site of union there were two firm bulbs linked by a constricted zone. This segment was resected and the nerve resutured. In the absence of any recovery tendon transplantations were prematurely undertaken 19 weeks after the second repair.

When first examined by me, 121 weeks after the second suture, the *extensores carpi radiales*, *extensor digitorum communis* and *abductor pollicis longus* were contracting strongly and the brachio-radialis weakly. It was not possible to estimate accurately the condition of the remaining muscles owing to the tendon transplantations, which adversely affected function.

CASE 243.—On August 17, 1943, J.H.B. sustained a perforating bullet wound of the left arm, resulting in a comminuted fracture of the lower third of the shaft of the humerus. At the point of entry a linear scar, 7·5 centimetres long, extended upwards from the medial epicondyle. At the exit a large irregular scar (9·0 by 4·0 centimetres) involved the lateral supracondylar region and the outer aspect of the cubital fossa. There were extensive soft tissue injury, prolonged infection and considerable residual scarring. The ulnar nerve had been completely severed approximately 9·0 centimetres above the medial epicondyle and the nerve ends had been "approximated with a couple of sutures of linen thread" within 24 hours of the injury. The radial nerve was not seen in the wound, but complete loss of conduction was recorded; the posterior cutaneous nerve of the forearm was independently involved. When first examined by me 20 weeks after the injury the lesions of the radial and ulnar nerves were complete, the former being injured above the branches to the brachio-radialis.

TABLE II.

Radial Nerve: Progress and Extent and Quality of Recovery.

The cases have been listed as in Table I.

Case.	Return of Voluntary Contraction in Weeks Dating from the Time of Repair.						Extent and Quality of the Recovery. The range and power of the movements have been expressed as a percentage of those on the normal side. The value for the range precedes that for the power.									Residual Difference in Circumference of Forearms.	Sensation.	Interval in Weeks between Repair and Last Examination.
	B.R.	E.C.R.L.	E.D.C.	E.C.U.	A.P.L.	E.P.L.	Wrist Extension (with the Fingers Extended.)	Power of Grip.	Synergic Extension of the Wrist.	Extension of Fingers Simultaneously.	Independent Extension of Fingers.			Thumb.				
											Index.	Middle.	Little.	Radial Abduction.	Extension.			
282. I.G.C.	22	27	37	36	40	45	35/50	70	Good.	Full/25	Full/25	Full/50	Full/35	70/4	Full/50	5 mm.	N.R.	196
180. W.W.	28	20	31	31	34	42	Full/strong	35	Some.	Full/fair				Full/weak	Full/weak	N.M.	N.R.	52
225. H.J.P.	19–121[1]	19–121[1]	19–121[1]		19–121[1]											N.M.		121
248. W.R.L.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.										52 mm.	N.R.	220
166. J.C. . .			9	9	18	19–25	Full/full	70	Good.	Full/75	Full/4	Full/12	Full/7	Full/5	Full/20	0 mm.		240
332. O.J.P.L.	[3]	13–40	13–40	13–40	13–40	13–40	60/30	30	Some.	Full[2]/20	90/25	90/20	90/10	80/30	Full/20	25 mm.	N.R.	138
40. K.H.McN.	Intact	20	34	35	40	40	Full/full	70	Good.	Full/75	75/4	Full/35	75/5	80/35	Full/50	7 mm.	S.R.	330
221. W.J.W.	N.R.	N.R.	N.R.	N.R.	N.R.	N.R.										65 mm.	N.R.	214
12. J.S. . .			41–53	81–94	N.R.	N.R.												257
243. J.H.B.	23	23	N.R.	N.R.	N.R.	N.R.	25/G		None.								N.R.	178

B.R. = Brachioradialis; E.C.R.L. = *Extensor carpi radialis longus*; E.D.C. = *Extensor digitorum communis*; E.C.U. = *Extensor carpi ulnaris*; A.P.L. = *Abductor pollicis longus*; E.P.L. = *Extensor pollicis longus*; N.R. = no recovery; S.R. = some recovery.

[1] Times calculated from date of secondary suture.

[2] Slight drooping of index finger. G. = against gravity.

[3] There was no note in the records as to the condition of this muscle following the injury; it was contracting weakly when the patient was first examined by me 40 weeks after the repair. N.M. = not measured.

Exploration of the radial nerve was delayed by infection. Spontaneous recovery appeared in the brachio-radialis 43 weeks after the injury. Fifteen days later the nerve was explored in the supracondylar region. About midway between the epicondyle and the point where it passed anterior to the intermuscular septum the nerve entered scar tissue and what appeared to be a swollen neurogliomatous mass, which extended almost to the epicondyle. Just distal to this mass branches passed laterally to the brachio-radialis and *extensor carpi radialis longus* and medially to the brachialis; stimulation of the latter produced contraction of the lateral fibres of that muscle. Stimulation above the mass gave weak contraction of the brachio-radialis only. The scarred zone and neurogliomatous mass were excised and the branch to the brachialis was sacrificed. Preparation of the nerve ends was terminated with conditions still unfavourable for repair when union could just be effected without tension with the elbow fully flexed. The suture line was situated in an unfavourable field just above the lateral epicondyle at a point immediately above where the branches were passing laterally from the trunk; a satisfactory bed could not be prepared for the nerve.

Progress Report.—Recovery appeared in the brachio-radialis and *extensor carpi radialis longus* at 23 weeks; 54 weeks later these two muscles were contracting feebly. Successive examinations up to 178 weeks after repair indicated that no further motor recovery was to be expected. There was no sensory recovery.

CASE 248.—On December 6, 1943, W.R.L. sustained shrapnel wounds of the inner aspect of the right arm at the axillary outlet. Wide excision for gas gangrene resulted in extensive scarring. There was a complete lesion of the radial nerve below the branches to triceps. Plastic operations 22 weeks after the injury revealed a completely severed radial nerve in the brachio-axillary angle. The nerve ends were widely separated and buried in scar tissue; they were mobilized with difficulty. Considerable tension was required to approximate the nerve ends, which were inadequately prepared in order to permit end-to-end union. In the absence of any recovery 67 weeks later appropriate tendon transplantations were performed. There were no signs of regeneration 220 weeks after repair.

CASE 282.—On February 22, 1944, I.G.G.C. sustained an ax injury. This resulted in a laceration of the dorsum of the right arm which involved the radial nerve towards the lower end of the spiral groove. Two hours later, the nerve, which was almost completely severed, was sutured approximately 12·5 centimetres above the lateral epicondyle; the site of injury was above the origin of the branches to the brachio-radialis. The posterior cutaneous nerve of the forearm was independently damaged.

Progress Report.—Recovery was first observed in the brachio-radialis at twenty-two weeks and proceeded uninterruptedly for a further 23 weeks, by which time all muscles were contracting. The extent and quality of the motor recovery when the patient was last examined at 196 weeks are given in Table II. Forearm wasting had occurred to the extent of 3·0 centimetres at 22 weeks, but this had been reduced to 5·0 millimetres at the last examination. There was no significant sensory recovery in the superficial radial field, though there had been some reduction in the extent and depth of the sensory defect over the dorsum of the forearm.

CASE 332.—On June 11, 1945, O.J.P.L. sustained a perforating gunshot wound of the left elbow which resulted in complete loss of function in the field of the radial nerve. The wounds were not infected and healed to leave (*a*) an oblique linear entry scar, 4·0 centimetres in length, which extended upwards and inwards from a point 2·0 centimetres supero-medial to the medial epicondyle, and (*b*) an oblique linear exit scar, 5·0 centimetres in length, extending downwards and forwards from the lateral epicondyle.

Exploration 235 days after the injury revealed a severed nerve in the intermuscular furrow. Bulbs were present on the proximal and distal stumps. These were removed and the nerve was repaired. The site of repair was described as being below the source of the branches to the brachio-radialis and radial extensors of the wrist, but the latter were reported as being paralysed before the operation and again 13 weeks after suture.

Progress Report.—The patient was first examined by me 40 weeks after repair, when the brachio-radialis showed a residual paresis and the extensors of the wrist were contracting weakly and the remaining muscles feebly. Since that time there has been a progressive improvement in muscle function and when the patient was last examined at 138 weeks motor function had reached a state of recovery given in Table II. The posterior cutaneous nerve of the forearm had been independently involved. There was no significant sensory recovery in the field of this nerve and in that of the superficial radial nerve.

Radial Nerve Suture: Comments.

The recovery was classed as good in two early (Cases 180 and 282) and two late (Cases 40 and 166) repairs, with an additional late repair (Case 332)

progressing to a satisfactory end result. A good result was recorded in the one case of resuture. The absence of, or negligible, recovery in the remaining cases could be attributed to unfavourable local conditions for repair, such as the length of nerve destroyed, incomplete preparation of the nerve ends owing to unavoidable circumstances, and tension being required to effect end-to-end union.

The opinion has been expressed (Aird, 1947) that the results of repair of the posterior interosseous nerve are in general so unsatisfactory that no useful purpose is served by performing it. In this connexion the excellence of the recovery in one case (166) of this series is noteworthy.

TABLE III.

Radial Nerve: Information Relating to the Interval, in Months, Elapsing between Repair and the Onset of Recovery.

Investigator.	Level of the Repair.		
	Proximal Third of the Upper Arm.	Mid-third of the Upper Arm.	Distal Third of the Upper Arm.
Stopford	6 to 7	4 to 6	3 to 5
Stookey and Scarff ..		7 to 8[1]; 14[2]	6 to 7[1]; 12[2]
Björkesten	← Av. 8 →	Av. 6·6 →	
This inquiry		5 to 6	

[1] "Under good conditions." [2] "Under poor conditions." Av. = Average.

End result assessments show that in those cases in which repair was delayed the patients fared as well or better than those for whom early suture was performed, and that good recovery can occur even when repair is delayed for eleven months. A further point of interest is that in one case of late repair, in which the patient made a good recovery, the wound was originally grossly infected and healed with considerable scarring; this suggests that infection and scarring do not, *per se,* necessarily adversely affect the end result. The deleterious effects introduced by these factors would appear to be caused by increasing the length of nerve that must be excised before satisfactory conditions for end-to-end suture are obtained (see Section XVIII).

Following repair in the spiral groove and supracondylar region there is a delay of five to six months in the onset of voluntary contractions in the first muscle to be reinnervated. The onset and subsequent course of recovery in those cases showing good recovery followed much the same pattern regardless of when the nerve was repaired. Values given by Stopford (1920, excluding exceptional cases), Stookey and Scarff (1943) and Björkesten (1947) for the onset of recovery in the first muscle to be reinnervated are shown in Table III. The conditions obtaining in the individual cases from which their data were derived were not given by them.

Recovery in the proximal musculature exceeded that in the distal. The reason for this is fully discussed in Section XVII.

The poor sensory recovery calls for comment, particularly when this finding is examined in the light of evidence to the effect that 29% of the cross-sectional area of the radial nerve is occupied by cutaneous fibres (Sunderland and Bedbrook). It is believed that the funicular grouping at levels where the repairs were executed was such that the cutanous fibres occupied an independent group (Sunderland, 1945) and that, with the dissimilarity of the funicular patterns in the opposed nerve ends, wasteful regeneration of these fibres was particularly favoured.

2. *Median Nerve Suture: Case Records.*

CASE 37.—On May 7, 1942, R.S.U. was involved in a truck accident, in which a large piece of glass was driven through his right forearm. The wound became infected and, when it healed, left a linear scar extending down the mid-volar surface of the forearm from the apex of the cubital fossa and a curved scar crossing the ulnar surface of the forearm 7·5 centimetres below the medial epicondyle. There was complete loss of function in the fields of the median and ulnar nerves, which were involved below the supply to the forearm muscles.

Exploration 143 days after the injury revealed an irreparably injured ulnar nerve and a severed median nerve whose proximal and distal stumps entered and were widely separated by a mass of dense scar tissue. There were no bulbs. After freeing of the nerve ends it was obvious that a suitable repair could not be effected. Suture under tension left a gap of 8·0 millimetres separating the nerve ends.

There were no signs of recovery in the median field 62 weeks after the repair.

CASE 46.—On the night of May 14, 1942, B.M.M. lacerated his left wrist on broken glass. The following structures, which had been severed, were repaired the following morning: median nerve, *flexor carpi ulnaris*, *flexor carpi radialis*, *palmaris longus*, tendon of *flexor digitorum sublimis* to the index finger and the *flexor pollicis longus*. No further details were available.

Progress Report.—The patient was first examined by me at nine weeks. A bulb was palpated on the nerve at the site of repair beneath a ragged transversely directed scar. There were no signs of sensory recovery, but feeble voluntary contractions of muscle fibres could be detected along the wasted radial margin of the thenar eminence. Signs of sensory recovery were evident at 15 weeks. The patient was transferred to another centre at 22 weeks, when motor and sensory recovery had reached the stage given in Tables V and VI. Further records were not available.

CASE 108.—On October 14, 1942, H.J.G. lacerated his right wrist on broken glass. The wound was treated as a simple laceration and healed by primary intention to leave a linear scar, 5·0 centimetres in length, crossing the wrist creases obliquely. The patient was first examined by me 16 weeks after injury, when there was complete loss of function in the field of the median nerve. Exploration 172 days after the injury revealed a severed nerve. The proximal stump terminated in a bulb, which was connected to the distal stump by scar tissue. The scar tissue was excised and the nerve ends suitably prepared and sutured without tension with the elbow and wrist partially flexed.

Progress Report.—The opponens and *abductor pollicis brevis* commenced to contract six to ten weeks after repair. The patient was transferred to another State 16 weeks after repair and no further assessments could be obtained. The condition of the motor and sensory fields recorded at the last examination are given in Tables V and VI.

CASE 167.—On December 30, 1940, A.J.S. sustained a perforating bullet wound of the lower third of the right forearm. The point of entry was in the middle of the volar surface, 9·0 centimetres above the wrist. The point of exit was on the dorsal aspect of the ulnar border, 7·0 centimetres above the wrist. There was complete loss of function in the field of the median nerve.

The nerve was explored 168 days after the injury. It was buried in dense fibrous tissue; the nerve had been severed and the ends were joined by fibrous tissue. There were no bulbs. The involved section was excised and the nerve ends were united with the wrist in full flexion. Further information relating to the repair was not available.

Progress Report.—Excluding a reference to the effect that there was no recovery 19 weeks after repair, there were no reports of the result of the suture. The patient however, was later reaccepted class A in the army and returned to full service duties.

The patient was first examined by me at 100 weeks. Four months previously he had fallen on his outstretched right arm. He felt "something give" in his forearm, following which, he claimed, many of the symptoms present prior to repair returned. According to him the hand, prior to the fall, had functioned "perfectly well". Examination revealed severely paresed thenar intrinsic muscles and complete sensory loss involving the palm, thumb and radial two and a half digits. The involved skin was healthy and unscarred, but callosed from hard manual labour. It was felt that this condition could not have developed in the face of long-standing anæsthesia; this suggested that sensory recovery after repair had been well advanced and had remained so until the fall.

The state of nerve function was unchanged five weeks later, when the patient was discharged from the army. When he was next examined, 60 weeks later, movements attributable to the intrinsic muscles of the thumb were poorly and weakly executed; the muscles, however, responded briskly and strongly to electrical stimulation. The entire cutaneous field was sensitive to pinprick and light touch, though the sensations

TABLE IV.

Median Nerve: Information Relating to the Injury and Conditions of Repair.

The cases have been grouped according to the causative injury and the duration of the interval between injury and repair.

Case and Nature of Injury.	Age.	Level of Suture in Centimetres.	Interval between Injury and Suture.	Infection.	Scar.	Length of Nerve Destroyed.	Tension.[1]	Treatment of Nerve Ends.	Suture Material.
Laceration:									
46. B.M.M.		Wrist.	Few hours.	Nil.	Nil.	Information not provided[2]			
226. A.J.A.	40	Wrist.	Few hours.	Nil.	Nil.	Negligible.	No.	Adequate.	Deknatal.
236. —.H.	22	Wrist.	Few hours.	Nil.	Nil.	Information not provided[2]			
314. L.F.W.	26	Wrist.	Few hours.	Nil.	Nil.	Information not provided[2]			
337. K.B.C.	20	Wrist.	Few hours.	Nil.	Nil.	Information not provided[2]			
173. C.McK.	27	Wrist.	2 days.	Nil.	Nil.	Information not provided[2]			Catgut.
37. R.S.U.		Junction of mid and upper third of forearm.	143 days.	I.	S.	Considerable.	Yes.	Inadequate.	Black silk.
108. H.J.G.		Wrist.	172 days.	Nil.	Nil.	Small.	No.	Adequate.	Black silk.
284. F.E.B.		Wrist.	2+ years.	Nil.	Nil.	Intermediate.	No.	Adequate.	Black silk.
Gunshot wound:									
322. O.A.R.	31	16·0 above the medial humeral epicondyle.	123 days.	Nil.	S.	Considerable.	Yes.	Adequate.	Black silk.
167. A.J.S.	28	8·0 above distal wrist crease.	168 days.	Nil.	S.	Information not provided.			
333. J.R.L.	23	Cubital fossa.	245 days.	I.	S.	Considerable.	No.	Inadequate.	Deknatal.
Gunshot wound plus bone injury:									
287. L.G.G.	25	Junction of mid and upper third of forearm.	196 days.	Nil.	S.	Intermediate.	No.	Adequate.	Human hair.
275. J.P.L.	21	Mid-forearm.	310 days.	I.	S.	Considerable.	Yes.	? Adequate.	Wire and black silk.

Length of nerve destroyed: 1 to 4 mm. = negligible; 5 to 10 mm. = small; 11 to 30 mm. = intermediate; 30+ mm. = considerable. I. and S. = significant infection and scarring respectively.

[1] Tension after mobilization and flexion.

[2] In these cases the tissues had been cleanly severed. The evidence suggested that a negligible length of the nerve had been destroyed, that the nerve ends were in a suitable condition for union, and that the latter was effected without tension.

TABLE V.

Median Nerve: Progress, Extent and Quality of Motor Recovery.

The cases have been listed as in Table III.

Case.	Interval in Days between Injury and Repair.	Return of Voluntary Contraction in Weeks Dating from the Time of Repair.	Interval in Weeks between Repair and Last Examination.	Extent and Quality of Recovery Expressed in Terms of or as a Percentage of that Obtaining on the Normal Side.	Residual Wasting in the Median Field in the Hand.
46 B.M.M.	Few hours.	Th. 0 to 9.	22	Weak movements of palmar abduction of the thumb. No thenar rotation on opposition.	Present.
226 A.J.A.	Few hours.	Th. 20 to 25.	40	Palmar abduction of the thumb correctly executed through a full range against strong resistance. Good thenar rotation in opposition.	Trace only.
236 —.H.	Few hours.	Not known.	312	All thenar movements correctly, fully and strongly executed.	Trace only.
314 L.F.W.	Few hours.	Th. 23 to 29.	62	Palmar abduction of the thumb correctly executed through a full range against strong resistance. Range of thenar rotation in opposition: 50.	Trace only.
337 K.B.C.	Few hours.	Th. 1 to 180.	252	Feeble thenar movements.	Present.
173 C.McK.	2	Th. 26 to 83.	255	Palmar abduction of the thumb. Range: Full. Power: 15. Range of thenar rotation in opposition: 50.	Trace only.
37 R.S.U.	143	No recovery.	62	No recovery.	Present.
108 H.J.G.	172	Th. 6 to 10.	16	Feeble thenar movements.	Present.
284 F.E.B.	2+ years.	Th. 4 to 8.	26	Palmar abduction of the thumb correctly executed through a full range against strong resistance. Good thenar rotation in opposition.	Present.
322 O.A.R.	123	P.T. 30. F.C.R. 58 to 72.	176	Weak contractions of the *pronator teres* and *flexor carpi radialis*.	Considerable.
167 A.J.S.	168	Th. 19 to 100.	165	Feeble thenar movements.	Present.
333 J.R.L.	245	P.T. and F.C.R. 27 to 34. F.D.S. 47 to 67. F.P.L. and Th. 92 to 117.	157	P.T. and F.C.R. contracting strongly and the remainder weakly. Thenar movements with the exception of flexion of the terminal phalanx are very good; this is principally due to the compensatory activity of the ulnar supplied fibres of the intrinsic muscles but recovery in the median field is a contributing factor.	Present.
287 L.G.G.	196	Th. 6 to 44.	191	All thenar movements correctly, fully and strongly executed.	Trace only.
275 J.P.L.	310	Th. 93 to 107.	211	Defective thenar movements.	Present.

[1] Th. = Thenar group; P.T. = *Pronator teres*; F.C.R. = *Flexor carpi radialis*; F.D.S. = *Flexor digitorum sublimis*; F.P.L. = *Flexor pollicis longus*.

elicited were appreciated better over the palm than over the digits and were less distinct than on the sound side. The extent and quality of the motor and sensory recovery are given in Tables V and VI.

CASE 173.—On March 20, 1943, C.McK. lacerated the volar aspect of his left forearm just above the distal wrist crease. Two days later two tendons of the *flexor digitorum sublimis*, the *flexor carpi radialis* and the *palmaris longus* were sutured. The ends of

the severed median nerve were found and accurately joined, "care being taken to see that the sheath of the nerve was in apposition all around". The wound was washed in 1 in 1,000 acriflavine solution before closure; it healed without becoming infected. The opponens and *abductor pollicis brevis* were paralysed; the thumb could not be abducted at right angles to the palm or internally rotated.

Progress Report.—Cutaneous sensation reappeared in the palm 22 to 26 weeks after repair; at the latter date the thenar eminence was very wasted and there was no motor recovery. When the patient was next examined 57 weeks later only a trace

TABLE VI.

Median Nerve: Extent and Quality of Sensory Recovery.
The cases have been listed as in Table III.

Case.	Interval in Days between Injury and Repair.	Interval in Weeks between Repair and Last Examination.	Cutaneous Sensation.				Joint Sensation.	Trophic Disturbances (Excluding Spindling of the Index Finger).
			Palm.	Thumb.	Index.	Middle.		
46. B.M.M.	Few hours.	22	P2	P2 (at base of digits)			No improvement.	Present.
226. A.J.A.	Few hours.	40	P4–5 T4 D1 T°2	P4 T1 D0 T°1	P4–5 T4 D1 T°2	P4 T1 D0 T°1	Improved but still defective.	Absent.
236. —.H. . .	Few hours.	312	P4; T4; D1; T°2–3				Improved but still defective.	Absent.
314. L.F.W.	Few hours.	62	P3 T1 D0 T°1	P1 T0 D0 T°1	P1 T0 D0 T°1	P3 T1 D0 T°1	No improvement.	Absent.
337. K.B.C.	Few hours.	252	P2; T0; D0; T°1				No improvement.	Absent.
173. C.McK.	2	255	P4; T4; D0; T°2				Improved but still defective.	Absent.
37. R.S.U.	143	62	No recovery.				No improvement.	Present.
108. H.J.G.	172	16	No recovery.				No improvement.	Present.
284. F.E.B.	2+ years.	26	Terminal one and a half phalanges of the thumb, index and middle fingers: P1, T4. Elsewhere P4, T4.				Not tested.	Present.
322. O.A.R.	123	176	P4 T3–4 D0 T°3	P2–4 T3–4 D0 T°1–2	P1–4 T3–4 D0 T°1	P1–2 T0 D0 T°1	Improved but still very defective.	Present.
167. A.J.S. . .	168	165	P4 T4 D0 T°1	P2; T3; D0; T°1			Improved but still defective.	Absent.
333. J.R.L.	245	157	P3–4 T3 D0 T°1	P3; T2–3; D0; T°1			No improvement.	Absent.
287. L.G.G.	196	191	P2–3 T2	P2–3; T1			Improved but still defective.	Absent.
275. J.P.L.	310	211	P4 T4 D0 T°2–3	P3–4 T3 D0 T°2–3	P3–4 T3 D0 T°2–3	P2–3 T1–3 D0 T°1–2	Improved but still very defective.	Absent.

of wasting was visible and all thenar movements could be executed against resistance. The thumb and fingers were still insensitive, but the entire palmar field was hyperalgesic. Despite the sensory defect, the patient, a barman, could, under visual control, handle glasses dexterously for the first time since his injury. This was due to the marked improvement in motor function.

The patient was last examined at 255 weeks. Only a trace of wasting of the thenar eminence was then discernible. A bulb was palpable on the nerve at the site of repair. Individual thenar movements could be fully executed against resistance, though rotation of the thumb in opposition was reduced by about half; coordinated movements, performed in association with other digits, were well executed. The state of the motor and sensory functions is shown in Tables V and VI.

CASE 226.—On November 4, 1943, A.J.A. lacerated his right wrist with a razor, severing the *palmaris longus* tendon (not repaired), ulnar artery (ligated) and median nerve, which was sutured a few hours later. The nerve had been cleanly severed; the ends were not trimmed and were united without tension.

Progress Report.—Cutaneous sensation reappeared at 14 weeks, when pinprick in the palmar field gave rise to a diffuse intense stinging sensation. The opponens and *abductor pollicis brevis* commenced to contract six to eleven weeks later. Restoration of function was such as to warrant the patient's return to duty at 40 weeks. All movements were then full in range and strongly executed; wasting of the thenar eminence was evident, though it had been greatly reduced. Cutaneous sensation was approaching normal limits in the palm and index finger; the residual sensory defect was maximal in the thumb and middle finger (Tables V and VI).

CASE 236.—H., a serviceman, presented for examination on January 1, 1944, with a history of aching and tenderness in the right wrist and hand, which dated from a session of heavy manual labour in a quarry some days previously. He was referred for examination because of a previous injury to his median nerve. Six years previously he had lacerated his right wrist. The wound healed to leave a large irregular scar crossing the wrist, which was adherent to the deeper structures. The only information available was that the median nerve, a blood vessel and some tendons had been severed and that the nerve had been repaired.

Examination on January 1, 1944, revealed excellent function in the median field. A bulb was present on the nerve at the site of repair. There was only a trace of wasting, all thenar movements were correctly, fully and strongly executed (though there was some residual paresis compared with the sound side), while sensation was little short of normal (Tables V and VI). The aching and tenderness responded to treatment and the patient was returned to service 40 days later.

CASE 275.—On November 24, 1943, J.P.L. sustained a machine-gun bullet wound of the left forearm, which resulted in (*a*) large gaping wounds on the front and back of the radial side of the mid-third of the forearm with considerable soft tissue destruction, (*b*) a comminuted fracture of the shaft of the radius at the junction of the middle and distal thirds. "No obvious nerve damage was seen" was reported in the operation notes, though a median nerve lesion was subsequently recorded. The wound became infected; discharging sinuses and the removal of sequestra required attention for six months.

When first seen by me 16 weeks after the injury there was complete loss of function in the fields of the median and superficial radial nerves and in the field of the posterior division of the lateral cutaneous nerve of the forearm. The median nerve was explored 310 days after the injury. The proximal stump terminated in a large firm bulb just below the arch of the *pronator teres*. The distal stump terminated in a large mass of dense scar tissue at the junction of the middle third and distal third of the forearm. Local conditions were particularly unfavourable for repair. Removal of the bulb and freshening the distal stump left a gap which could just be closed by fully flexing the wrist and elbow; funiculi were seen in the presenting surfaces, but both stumps were firmer than normal. Union was effected under slight tension.

Progress Report.—The opponens and *abductor pollicis brevis* commenced to contract 93 to 107 weeks after repair; when last examined at 211 weeks the associated movements were feeble and lacked coordination. Motor function was grossly impaired by the damage to soft tissues of the forearm as well as by poor recovery in the intrinsic muscles.

The palmar field was tender to pressure at ten weeks. The overlying skin was still insensitive four weeks later, but when the patient was next examined a further 56 weeks later, pinprick elicited a burning, stinging sensation, which radiated widely. The extent and quality of the recovery when the patient was last examined at 211 weeks is given in Tables V and VI.

CASE 284.—F.E.B. was first examined by me more than two years after he had lacerated his left wrist; he stated that severed tendons had been sutured. There was a healed transverse linear scar crossing the volar aspect of the forearm just above the proximal wrist crease and a complete lesion of the median nerve.

Exploration 28 days after the patient presented for examination revealed a severed nerve. The proximal stump terminated in a soft bulb, which could not be palpated before operation. This bulb was connected by a short, narrow strand of fibrous tissue to the shrunken distal stump (reduced in calibre by approximately one-half), which carried a very small, firm swelling. Stimulation failed to elicit a response. There was very little scar tissue in the region and the nerve ends were easily freed. The bulbs were removed and the nerve ends suitably trimmed; they were easily united with the wrist flexed.

Progress Report.—There was no recovery one week after repair. The patient was not reexamined until three weeks later, when an improvement in sensory function

was already evident. Pinprick over the radial side of the middle finger and the adjacent portion of the palm (previously insensitive) produced an intense, widely radiating, stinging sensation. Elsewhere pinprick elicited a sensation of contact while light touch, though defective, was appreciated, but, curiously, immediately the gentle stimulus was replaced by firm pressure the patient lost all appreciation of any sensation. This observation was confirmed by a number of observers. There was no two-point discrimination and no temperature sensibility. Contractions commenced in the opponens and *abductor pollicis brevis* 28 to 59 days after repair. Seven weeks later the ulnar nerve was blocked with "Novocain" to investigate the innervation of the thenar intrinsic muscles; recovery in the opponens and *abductor brevis* was confirmed. The *flexor pollicis brevis* was innervated by the ulnar nerve. The patient returned to service duties at 18 weeks. An examination eight weeks later revealed that recovery was well advanced in the originally involved thenar muscles; all thenar movements were well executed. Pinprick over the terminal one and a half phalanges of the thumb, index and middle fingers was interpreted as contact, but light touch was localized and appreciated at low thresholds. Elsewhere sensation had reached a stage of recovery shown in Table VI. Trophic ulcers were present on the dorsum of the index and middle fingers and had been aggravated by contact with petrol, oil and grease.

CASE 287.—On August 23, 1943, L.G.G. sustained a perforating bullet wound of the right forearm. The upper third of the radius was fractured and conduction in the median nerve completely interrupted. The wounds healed, to leave an entry scar, 3·0 centimetres long, extending down the mid-line of the dorsum of the forearm from a point 7·5 centimetres below the lateral epicondyle and a circular exit scar on the inner aspect of the forearm, 6·0 centimetres below the medial epicondyle. Some sensory recovery in the median field was recorded 20 weeks later. The nerve was explored, 196 days after the injury, at the junction of the proximal and middle third of the forearm. It had been almost completely severed and, at the site of injury, was connected by scar tissue to the healed fracture; there were no bulbs. The ends of the severed portion of the nerve were separated by and involved in a mass of scar tissue. This was excised, the ends freshened and the nerve repaired.

Progress Report.—The patient was first examined by me 43 days after the repair. The thumb, index and middle fingers were anæsthetic and the palmar cutaneous field was hyperalgesic. There was a residual paresis of the *flexor pollicis longus* and *flexor digitorum sublimis* to the index finger; the remaining extrinsic muscles were contracting normally. The opponens and *abductor pollicis brevis* were not contracting. The absence of information in the records relating to motor function made it impossible to assess whether the partial suture had contributed to the motor function recorded at this examination. When the patient was next examined at 44 weeks the *abductor pollicis brevis and opponens* were contracting and there had been further improvement in sensation.

The extent and quality of the recovery present when the patient was last examined at 191 weeks is given in Tables V and VI. The course of recovery strongly suggested that the restoration of cutaneous sensation in the thumb and digits and of motor function in the opponens and *abductor pollicis brevis* were due to the suture.

CASE 314.—On July 2, 1944, L.F.W. lacerated his right wrist. The median nerve was severed and repaired with sheath sutures a few hours later. No further information was available. The wound healed by primary intention, leaving an irregular scar crossing the wrist just above the proximal crease.

Progress Report.—Cutaneous sensation reappeared at 14 weeks, when pinprick about the thenar crease, 95 millimetres distal to the suture, sent an unpleasant tingling sensation into the index finger. The opponens commenced to contract 9 to 15 weeks later.

When the patient was last examined at 62 weeks median nerve function was stationary. There was a bulb on the nerve at the site of repair. The recovery in the opponens and *abductor pollicis brevis* had resulted in a marked filling out of the thenar eminence. All thenar movements were well executed against resistance with the exception of internal rotation. The patient, a farmer, complained that the thumb became useless after an hour's hard work. The state of motor and sensory function at the last examination is given in Tables V and VI.

CASE 322.—On October 21, 1944, O.A.R. sustained a gunshot wound involving the medial aspect of the upper third of the left arm. The ulnar and median nerves and the brachial artery were severed and there was considerable soft tissue damage. The wound healed slowly, leaving a large, irregular, adherent scar. This delayed repair of the nerves, which were not explored until 123 days after the injury. There were no bulbs and the nerve ends were lost in dense fibrous tissue. Suitable preparation of the nerve ends and removal of the intervening scar tissue left a gap of 5·0 centimetres in the median nerve and one of 8·0 centimetres in the ulnar. With

the elbow and wrist fully flexed the median was sutured under moderate tension and the ulnar under such considerable tension that it was thought advisable to reexplore and resuture it. This was done 104 days later, when union was effected without tension with the elbow and wrist again fully flexed. Union of the median nerve appeared satisfactory.

Progress Report.—The *pronator teres* commenced to contract at 30 weeks, while pinprick over the thenar eminence first elicited a painful response 10 weeks later. Regeneration proceeded very slowly, sensory recovery advancing ahead of motor. The state of motor and sensory function when the patient was last examined, 176 weeks after repair, is given in Tables V and VI.

CASE 333.—On February 23, 1945, J.R.L. sustained extensive mortar bomb wounds of the right elbow. There was mild sepsis of the wounds, with complete loss of function in the field of the median and ulnar nerves, and the brachial artery was twice ligated—once in the wound and later in the mid-upper arm. Soft tissue damage was considerable. The patient was first examined by me 56 days after the injury. There were extensive multiple scars medial to the biceps in the cubital fossa and supracondylar region, and an elongated scar superficial to the neuro-vascular bundle which extended the full length of the upper arm. Loss of median nerve function was still complete; the ulnar nerve was regenerating spontaneously.

The median nerve was explored in the cubital fossa 140 days after the injury. The ulnar nerve was also exposed; it was in continuity, healthy in appearance, and stimulation resulted in the contraction of all muscles supplied by it. The median nerve was traced, in continuity, through dense fibrous tissue. About 2·0 centimetres of its length were fibrosed and a small bulb was present at the proximal end of this segment. The nerve did not respond to stimulation. Below the scarred section the nerve appeared normal. The fossa was cleared of fibrous tissue and the nerve left crossing it. The wound was then closed.

Reexploration 245 days after the injury revealed conditions which were the same as those previously observed. The bulb and scarred section, about 5·0 centimetres in length, were excised and ends, in which some fibrous tissue was still presenting, united. Tension was avoided by fully flexing the wrist and elbow. Further trimming of the nerve ends was desirable but impracticable.

Progress Report.—The *pronator teres, flexor carpi radialis* and *palmaris longus* commenced to contract 27 to 34 weeks after repair. Signs of sensory recovery made their appearance at 47 weeks, when pinprick and very light stroking of the thenar eminence resulted in a tingling sensation which was felt along the radial side of the index finger.

Recovery was still proceeding when the patient was last examined 157 weeks after repair; the extent and quality of the motor and sensory functions on that occasion are given in Tables V and VI.

CASE 337.—On April 2, 1943, K.B.C. lacerated his left wrist. The ulnar nerve and artery, the median nerve, and the tendons of the *palmaris longus, flexor pollicis longus* and *flexor digitorum sublimis* and *profundus* were severed. These were repaired a few hours later, but no details were provided. The patient was first examined by me at 180 weeks. The intrinsic muscles of the hand were contracting and there was evidence of sensory recovery in both median and ulnar fields. A large bulb was palpable on each nerve at the site of suture. Subsequent examinations revealed that the condition was stationary; the state of motor and sensory function at the last examination, 252 weeks after repair, is given in Tables V and VI.

Median Nerve Suture: Comments.

1. The significant factor in an assessment of the end result is the extent of the recovery of useful sensation (cutaneous and joint) in the hand. There is usually a substantial overlap of the ulnar supply to the thenar intrinsic musculature, which, together with compensatory movements, reduces the motor disability. Impairment of dexterous movements of the thumb and index finger, however, cannot be neglected in this connexion.

The end result was assessed as good in three cases (173, 226, 236), satisfactory in four (167, 275, 287, 333), fair in two (314, 322) and poor or negligible in two (37, 337). In three (46, 108, 284) recovery was progressing favourably when the patients were last examined, but the short period of post-operative observation did not permit a true assessment of the end result.

2. An analysis of the end results indicates that satisfactory recoveries can follow repair which has been delayed for periods up to 10 months.

3. In general, cases of repair following laceration severance of the nerve fared better than those in which a missile was responsible for the injury. This can be attributed to:

(i) The much greater length of nerve destroyed in the gunshot group owing to the greater severity of the causative injury and the more extensive intraneural changes introduced by infection and scarring. This resulted in a greater dissimilarity in the funicular patterns of the nerve ends at the suture line and also necessitated union under tension, both of which reduce the chances of a successful repair.

(ii) The level and nature of the injury. There is evidence that the retrograde neuronal reaction incidental to nerve injury is proportional to the proximity of the lesion to the parent cell and to the violence of the injury. In the gunshot group the lesions were severer and were situated at higher levels than in the laceration group, where the nerve was most commonly involved at the wrist. For these reasons the retrograde changes, which influence the extent and quality of the regeneration, are likely to be more serious in the former than in the latter. Furthermore, at and above the elbow the sensory and motor fibres for the hand are so scattered throughout the funiculi comprising the nerve, and intermingled with fibres from other sources, that there is a much greater risk of the erroneous cross-shunting of regenerating axons during recovery. This results in the loss of axons down unrelated endoneural tubes and to a disturbance of the peripheral pattern even when they grow down functionally related, but not their original, tubes (see Section XVII). At the wrist, on the other hand, the fibres comprising the nerve are all destined for the hand, while those for the various terminal branches are well localized in separate funiculi or groups of funiculi. In this region, however, the nerve is composed of a large number of rather widely separated funiculi, so that where there is any dissimilarity in the funicular pattern at the nerve ends, the arrangement favours the loss of regenerating axons down interfunicular spaces. For this reason, when preparing the nerve ends for repair it is essential to avoid any unnecessary resection of nerve tissue. The best results were obtained following repair at the wrist when little or no trimming of the nerve ends was employed. Despite the morphological disadvantage just outlined, which somewhat offsets the advantage of branch localization of fibres, there is usually a better recovery in the functionally significant section of the median field following repair at the wrist.

(iii) The delay for considerable periods of repair following gunshot injuries. It is doubtful, however, whether delays of the duration obtaining in the present series of cases played any significant role in restricting the recovery. Thus good recoveries, which were either generalized or confined to certain sections of the field, were observed in both the laceration and gunshot groups after repairs that had been delayed for periods up to 10 months. The findings suggest that factors (i) and (ii) above play a more important role in limiting the ultimate recovery than factor (iii). There is evidence, however, that delays exceeding a year (which were not covered by the present inquiry) have an adverse effect on recovery. The influence of the interval elapsing between injury and repair on the extent and quality of recovery will be discussed in detail in Section XVI.

4. Motor and sensory functions were observed to return at the times set out in Table VII.

As a generalization it may be stated that following repair at the wrist, signs of cutaneous sensory recovery can be expected in the hand within three to five months, while voluntary contractions may reappear in the thenar

muscles as early as two months or be delayed for as long as five to six months. The onset and subsequent course of recovery after early and delayed repair were substantially the same.

Following the repair of gunshot injuries at and above the elbow (Cases 322 and 333) it would seem that the return of function is delayed for seven

TABLE VII.

Case Number.	Time of Return of Motor Function (Thenar Muscles).	Time of Return of Sensory Function.
(i) *Lacerations of the wrist:*		
46	0 to 9 weeks	15 weeks
108	6 to 10 weeks	—
173	26 to 83 weeks	22 to 26 weeks
226	20 to 25 weeks	14 weeks
284	4 to 8 weeks	1 to 4 weeks
314	23 to 29 weeks	14 weeks
(ii) *Gunshot injury:*		
275. Mid forearm ..	93 to 107 weeks	14 to 70 weeks
287. Upper forearm ..	6 to 44 weeks	1 to 6 weeks
322. Mid upper arm ..	30 weeks (*Pronator teres* and *flexor carpi radialis*)	40 weeks
333. Elbow	27 to 34 weeks (*Pronator teres* and *flexor carpi radialis*)	47 weeks

to eight months in the medial epicondylar muscle mass and 10 to 12 months in the cutaneous areas in the hand. It is to be noted, however, that the conditions at the suture line in these cases were considered to be unfavourable for recovery.

Values given by Stopford (1920, excluding exceptional cases), Stookey and Scarff (1943), and Björkesten (1947) for the onset of returning function are shown in Table VIII; the conditions obtaining in the individual cases from which their data were derived were not given by them.

TABLE VIII.

Median Nerve. Information Relating to the Interval, in Months, Elapsing between Repair and the Onset of Recovery

Investigator.	Level of the Repair.		
	Proximal Half of the Upper Arm.	Distal Half of the Upper Arm and Elbow.	Wrist.
Stopford		P.T. and F.C.R.: 3 to 7.	Sensation: 3 to 5.
Stookey and Scarff	Site of recovery not stated: 12 to 14[1]; 22[2].	Site of recovery not stated: 8 to 9[1]; 15[2].	4 to 5[1]; 10[2]; not stated whether motor or sensory.
Björkesten ..	P.T. and F.C.R.: Average 7·5.	P.T. and F.C.R.: Average 7·2.	Motor: Average 8·9.
This Inquiry ..		P.T. and F.C.R.: 7 to 8. Sensation in hand: 10 to 12.	Sensation: 3 to 5. Motor: 2 to 6.

P.T. = *Pronator teres.* F.C.R. = *Flexor carpi radialis.* [1] = "Under good conditions." [2] = "Under poor conditions."

5. The onset of recovery in the thenar muscles was delayed for longer periods after the repair of gunshot injuries, which were situated proximal to the mid-forearm, than after the repair of laceration injuries at the wrist. The greater delay in the gunshot group could have been due only in part to the greater distance to be covered by the regenerating axons, which suggests that other factors contributed to the delay. Such a belief is supported by the observation that after repair at and above the elbow the onset of recovery was unduly delayed even in those muscles which were innervated by short branches taking origin from the nerve just below the suture line. At such

levels the fibres representing these branches are discretely localized in the nerve so that the intraneural arrangement favours an early recovery in these muscles. Despite this advantage, the onset of recovery was unduly delayed.

The pattern of recovery following immediate, early and delayed repair at the wrist would indicate that, within the 10-month range covered by this inquiry, the time of repair is not *per se* the significant factor. An analysis of the data suggests that, though the distance to be covered by the regenerating axons is a contributing factor, the increased delay in the onset of recovery in the thenar muscles following repair after gunshot severance is principally due to the following facts.

(i) There is a greater delay in the entry of regenerating axons into the endoneurial tubes of the distal stump. This could in turn be due to: (*a*) a severer retrograde neuronal reaction in these lesions consequent on the more severe nature of the causative injury and the closer proximity to the cell body; (*b*) the fact that the suture line was subjected to stretch; (*c*) the greater dissimilarity in the funicular pattern on each side of the suture line as a result of the greater length of nerve destroyed.

(ii) Above the elbow the motor and sensory fibres for the hand are mixed and scattered over the majority of the funiculi comprising the nerve. The cutaneous fibres, however, occupy approximately 66% of the cross-sectional area of the nerve, while the fibres for the thenar muscles occupy only 4% of it (Sunderland and Bedbrook). Consequently, in the competition for endoneurial tubes in the distal stump, which occurs during regeneration, the cutaneous sensory axons have a decided advantage in reaching appropriate tubes. That this factor is operating is evidenced by the fact that signs of returning sensory function in the hand antedated the onset of recovery in the thenar muscles. However, the discriminative qualities of sensation either failed to recover or remained defective owing to the failure of many sensory dendrites to reach appropriate end organs and the confusion of the peripheral sensory pattern arising as the result of erroneous regeneration. In this connexion it should be noted that regenerating sensory fibres in the cutaneous plexuses respond, while still in an immature state, to stimuli which produce abnormal sensations. On the other hand, the anatomical restoration of the motor axonal pathway between the neuron and end organ is not alone sufficient for the restoration of function. Further changes, such as the maturation of the new pathways and their reestablishment in sufficient numbers, are necessary before voluntary contractions are possible (Sunderland, 1947).

(iii) The thenar muscles remain denervated for a longer time than the proximal musculature, which favours the development of those intramuscular complications which retard the restoration of function following reinnervation.

6. With few exceptions there was little return of joint sensibility even when good recovery occurred in the non-articular tissues innervated by the nerve. This residual defect greatly impaired the usefulness of the motor recovery.

7. The extent and quality of the recovery in cutaneous sensation in the median field was always better than that recorded for the thenar muscles innervated by the median nerve.

3. *Ulnar Nerve Suture: Case Records.*

CASE 38.—On January 18, 1942, J.L. sustained a perforating shrapnel wound of the lower end of the left forearm. The ulna was grazed and conduction interrupted in the ulnar nerve; 18 hours later a fragment was removed through the wound of entry. The wound healed without becoming infected. The exit and entry scars were situated 8·0 centimetres above the distal wrist crease. A large, tender bulb formed on the ulnar nerve beneath the exit scar. In the absence of spontaneous recovery the nerve was explored 191 days after the injury; it was buried for about 3·0 centimetres

TABLE IX.

Ulnar Nerve: Information Relating to the Injury and Conditions of Repair.

The cases have been grouped according to the causative injury and the duration of the interval between injury and repair.

Case and Nature of the Causative Injury.	Age at Time of Injury.	Level of Suture in Millimetres.	Interval in Days between Injury and Suture.	Infection.	Scar.	Length of Nerve Destroyed.	Tension.[1]	Treatment of Nerve Ends.	Suture Material.
Electrical burns:									
266. R.J.N.	31	Just above M.H.E.	724	Nil.	S.	Considerable.	Yes.	Inadequate.	Deknatal.
Compound fracture:									
328. G.I.T.	28	150 above R.S.L.	177	Nil.	Nil.	Intermediate.	No.	Adequate.	Black silk.
Laceration:									
139. E.D.B.	37	10 above R.S.L.	Few hours.	Nil.	S.	Negligible.	N.D.A.	N.D.A.	Black silk.
289. H.E.J.	23	Just above M.H.E.	Few hours.	Nil.	S.	Negligible.	No.	Adequate.	
307. J.A.P.B.	31	Wrist.	Few hours.	Nil.	Nil.	Negligible.	No.	Adequate.	Deknatal.
337. K.B.C.	20	Wrist.	Few hours.	Nil.	Nil.		N.D.A.		
290. A.B.R.	31	At M.H.E.	1	Nil.	Nil.	Negligible.	No.	Adequate.	Silk.
105. K.T.F.	34	250 above R.S.L.	2	Nil.	Nil.	Negligible.	No.	Adequate.	
325. E.H.	36	80 above R.S.L.	5	Nil.	S.		N.D.A.		
127. D.F.W.	19	At M.H.E.	56	Nil.	Nil.	Negligible.	N.D.A.	N.D.A.	
158. A.P.	42	25 above MH.E.	104	Nil.	S.	Considerable.	No.	Adequate.	Black silk.
269. C.T.B.	24	265 above R.S.L.	277	Nil.	Nil.	Considerable.	No.	Adequate.	Deknatal.
Gunshot wound:									
76. R.W.L.	28	Mid-forearm.	Few hours.	Nil.	Nil.	Negligible.	No.	Adequate.	Silk.
299. J.A.T.	31	Wrist.	Few hours.	Nil.	Nil.		N.D.A.		
75. G.W.S.	23	Upper third forearm.	6	I.	S.		N.D.A.		Black silk.
207. A.J.S.	20	60 above M.H.E.	131	Nil.	S.	Considerable.	No.	Adequate.	Black silk.
38. J.L.	25	80 above R.S.L.	191	Nil.	S.	Considerable.	No.	Adequate.	Black silk.
322. O.A.R.	31	160 above M.H.E.	227[2]	Nil.	S.	Considerable.	No.	Adequate.	Black silk.
183. C.P.C.	22	70 above M.H.E.	272	Nil.	Nil.	Considerable.	No.	Inadequate.	Linen.
277. R.R.V.	22	140 above M.H.E.	314	I.	S.	Considerable.	No.	Adequate.	Black silk.
Gunshot wound plus bone injury:									
243. J.H.B.	22	90 above M.H.E.	Few hours.	I.	S.	Not stated.	No.	Adequate.	Linen.
100. S.C.	21	60 above M.H.E.	320	I.	S.	Considerable.	Yes.	Inadequate.	Black silk.
242. J.J.	34	Junction mid- and distal thirds of forearm.	651[2]	I.	S.		N.D.A.		
321. F.W.K.	29	90 above M.H.E.	873	I.	S.	Considerable.	Yes.	Adequate.	
182. J.S.	37	At M.H.E.	960	I.	S.	Considerable.	No.	Adequate.	Black silk.
246. N.D.S.	28	160 above M.H.E.	1012	I.	S.	Considerable.	No.	Adequate.	Deknatal.

Length of nerve destroyed: 1 to 4 mm. = negligible; 5 to 10 mm. = small; 11 to 30 mm. = intermediate; 30+ mm. = considerable. M.H.E. = medial epicondyle of the humerus; R.S.L. = level of the tip of the styloid process of the radius; N.D.A. = no details available.

[1] Tension obtaining after mobilization, rerouting and posturing of the limb.

[2] Resuture.

of its length in dense scar. Dissection revealed a spindle-shaped mass across which intact bundles appeared to be passing. Stimulation above and below the swelling resulted in feeble contractions of some fibres of the hypothenar muscles. Further attempts at neurolysis resulted in a loss of response to stimulation. The involved section of the nerve was then resected and the nerve ends trimmed and united without tension with the wrist partly flexed.

Progress Report.—The hypothenar mass became tender to compression and the overlying skin hyperalgesic at 15 weeks. The hypothenar muscles commenced to contract two weeks later.

When the patient was last examined at 278 weeks, motor and sensory function had been stationary for two months. Details relating to the course of recovery and to the extent and quality of the end result are given in Tables X and XI. Despite the residual paresis, motor function was good.

CASE 75.—On January 3, 1941, G.W.S. sustained multiple shrapnel wounds of the right arm. Treatment, six days later, of wounds occupying the proximal two-thirds of the ulnar margin of the forearm revealed a completely severed ulnar nerve; "the ends were trimmed back and sutured with black silk and buried in muscle". The median nerve had also been injured. It was swollen and hæmorrhagic over 5·0 centimetres of its length; "the sheath was incised and nerve left intact though bruised". There was complete loss of function in the median field. Eighteen days later it was necessary to ligate the brachial artery in order to control hæmorrhage. The wound was infected and drained for 13 months.

The patient was first examined by me 96 weeks after the injury. Spontaneous regeneration in the median nerve had resulted in a condition just short of normal. There had been no recovery in the ulnar field. Exploration and resuture were refused by the patient. When he was last examined at 183 weeks there had been no recovery of motor function and only pressure was felt in the sensory field.

CASE 76.—On September 20, 1942, R.W.L. sustained a perforating bullet wound of the right forearm. The point of entry was marked by a small wound 4·0 by 1·5 centimetres just below the apex of the cubital fossa. At the point of exit there was a large wound 15·0 by 4·0 centimetres extending along the ulnar margin of the forearm from a point 4·0 centimetres above the distal wrist crease. Excision of the wound a few hours later revealed an almost completely severed ulnar nerve; only a strand of what appeared to be connective tissue linked the ends. Primary suture was performed.

Progress Report.—The ulnar field was paralysed and insensitive at seven weeks. When next examined, 14 weeks later, the hypothenar region and dorsum of the hand were hyperalgesic. Forty weeks after repair there was no motor recovery, but the entire cutaneous field was hyperalgesic, the ulnar one and a half digits being less sensitive in this regard; light touch was not appreciated. When next examined, 37 weeks later, all muscles supplied by the nerve were contracting, but flexion and abduction of the metacarpo-phalangeal joint of the little finger were the only movements which could be carried out against resistance. This was the last occasion on which the patient was examined; the stage to which recovery had progressed is given in Tables X and XI.

CASE 100.—On November 29, 1942, S.C. sustained a perforating bullet wound of the lower third of the left arm, resulting in a comminuted fracture of the shaft of the humerus at the junction of the middle and lower thirds. At the point of entry there was a small circular scar 5·0 centimetres immediately above the lateral epicondyle. At the point of exit there was a large, irregular, depressed scar, 8·0 centimetres in length, extending upwards along the medial surface of the arm from a point 5·0 centimetres above the medial epicondyle. Complete lesions of the ulnar and radial nerves were reported. Small sinuses discharged and sequestra required removal periodically for 12 months. Residual scarring was considerable. A large, tender neuroma developed on the ulnar nerve 7·0 centimetres above the medial epicondyle. Motor function in the radial field was fully restored (spontaneous recovery) 112 weeks after the injury.

Infection delayed exploration of the ulnar nerve until 320 days after the injury, at which time there were no signs of recovery. The nerve was exposed above and below the mass of dense fibrous tissue, which was beneath and continuous with the exit scar. The proximal stump ended in a large, hard bulb, which was adherent to and partly buried in this scar. Stimulation above the bulb resulted in questionable contractions of the *flexor carpi ulnaris*. The distal stump could be defined only where it emerged from the scar. The bulb, scarred tissue and neighbouring portion of the distal stump were excised. Further trimming of the nerve ends was desirable, but would have prevented suture; the nerve ends could only then be united under tension after transposing the distal stump in front of the epicondyle and fully flexing the elbow and wrist. Union was effected 6·0 centimetres above the epicondyle.

Before the operation the terminal phalanges of all four fingers could be fully and strongly flexed. That this was due to all sections of the *flexor digitorum profundus*

TABLE X.

TABLE X.

Ulnar Nerve: Progress, Extent and Quality of Motor Recovery.
The cases have been listed as in Table VI.

Case.	Interval, in Days, between Injury and Repair.	Return of Voluntary Contraction in Weeks, Dating from the Time of Repair.				Interval in Weeks between Repair and Last Examination.	The Range and Power of Movements Expressed as a Percentage of Those on the Normal Side. The value for the range precedes that for the power.									Residual Wasting in Mm.	
		F.C.U.	F.D.P.	H.	D.I.		F.C.U.	F.D.P.	Hypothenar Elevation in Opposition.	Flexion Little Finger.	Abduction Little Finger.	Adduction of Little Finger to Ring.	Abduction Index Finger.	A.P.	G.D.	Forearm.	Hand.
266. R.J.N. ..	724	7	7	77–197	N.R.	214	Strong.	Feeble.	None.	30/0	Full/0	N.R.	N.R.	N.R.	No.	5	14
328. G.I.T. ..	177			32	42	188			Some.	75/5	75/33	Flicker	Full/25	Feeble.	No.		19
139. E.D.B. ..	Few hours.			28	51	252			Normal.	Full/15	60/20	Flicker	35/30	Weak.	No.		15
289. H.E.J. ..	Few hours.	16	16	71[1]	[2]	192	Strong.	Strong.	None.	Feeble ments.	move-	N.R.	[2]	N.R.	Marked.	7	17
307. J.A.P.B. ..	Few hours.			75–192 31–56	N.R.	102			None.	Feeble ments.	move-	N.R.	N.R.	N.R.	Marked.		16
337. K.B.C. ..	Few hours.			1–180	1–180	252			Some.	45/G	30/3	0/0	0/0	N.R.	No.		10
290. A.B.R. ..	1	17	17	81	102	211	Strong.	Strong.	None.	Full/G	75/0	Feeble ments.	move-	Weak.	No.	+2	6
105. K.T.F. ..	2		16–23	40	65	200		Strong.	Some.	Full/ strong	60/ strong	Flicker	50/ weak	Weak.	No.		10
325. E.H.	5			40	54	180			None.	Feeble	moveme	nts.	33/ weak	Feeble.	No.		N.M.
127. D.F.W. ..	56	19	[2]	104–268	104–268	268	Strong.	[2]	None.	Feeble ments.	move-	0/0	0/0	Feeble.	Marked.	Nil	20
158. A.P.	104	18	18–44	85	109	237	Strong.	Strong.	None.	50/G	25/40	Flicker	50/G	Feeble.	Marked.	Nil	5
269. C.T.B. ..	277	11	18	46	62	227	Strong.	Strong.	Some.	Full/33	75/25	Flicker	33/15	Weak.	No.		Nil
76. R.W.L ..	Few hours.			40–77	40–77	77			Some.	60/ weak	60/ weak	0/0	10/0	Feeble.	Marked.		N.M.
299. J.A.T. ..	Few hours.			1–102	1-102	102			None.	Feeble ments.	move-	Flicker	Full/ weak	Feeble.	Marked.		18
75. G.W.S. ..	6			N.R.	N.R.	183			None.	N.R.	N.R.	N.R.	N.R.	N.R.			N.M.
207. A.J.S. ..	131	14	20	67	81	230	Strong.	Weak.	Trace.	Full/12	50/20	0/0	40/15	Weak.	No.	10	6
38. J.L.	191			17	47	278			Normal.	50/25	Full/15	Flicker	60/15	Weak.	No.		15
322. O.A.R. ..	227	117–128	N.R.	N.R.	N.R.	161	Feeble.	N.R.	None.	N.R.	N.R.	N.R.	N.R.	N.R.	No.		38
183. C.P.C. ..	272	28	[2]	63	[2]	221	Strong.	[2]	None.	Full/50	Full/30	Feeble	[2]	Feeble.	Slight.	4	10
277. R.R.V. ..	314	26	26	61	[2]	163	Feeble.	Feeble.	None.	5/0	5/0	Flicker	[2]	Feeble.	No.	40	28
243. J.H.B. ..	Few hours.	4–20	4–20	37	55	223	Strong.	Feeble.	None.	60/G	60/5	Flicker	60/G	Feeble.	No.		30
100. S.C. ..	320	30	[2]	67	93–128	140	Strong.	Weak.	None.	Flicker	Flicker	Flicker	Flicker	Feeble.	Slight.	25	40
242. J.J.	651			N.R.	N.R.	154			None.	N.R.	N.R.	N.R.	N.R.	N.R.	Marked.		N.M.
321. F.W.K. ..	873	1–56	N.R.	62–156	N.R.	156	Weak.	N.R.	None.	0/0	0/0	0/0	N.R.	N.R.	Marked.	17	36
182. J.S.	980	15	23–35	N.R.	N.R.	204	Strong.	Strong.	None.	N.R.	N.R.	N.R.	N.R.	N.R.	Marked.	23	26
246. N.D.S. ..	1012	27	38	68	N.R.	182	Weak.	Feeble.	None.	Flicker	Flicker	N.R.	N.R.	N.R.	Medium.		35

F.C.U. = *Flexor carpi ulnaris*; F.D.P. = *Flexor digitorum profundus*; H. = Hypothenar group of muscles; D.I. = first dorsal interosseous; A.P. = *Adductor pollicis*; G.D. = Griffe deformity; N.M. = present but not measured.

[1] No response to voluntary effort but responded to direct stimulation of the nerve at exploration 71 weeks after repair; contractions to voluntary effort returned 75 to 192 weeks after repair; N.R. = no recovery; 0/0 = the relevant muscles are contracting but not sufficiently strongly to produce movement; G. = can be executed against gravity only.

[2] Partly or entirely supplied by the median nerve.

TABLE XI.

Ulnar Nerve: Extent and Quality of Sensory Recovery.
The cases have been listed as in Table VI.

Case.	Interval in Days, between Injury and Repair.	Interval in Weeks, between Repair and Last Examination.	Cutaneous Sensation.			Deep Tissues, Reaction to Compression.	Joint Sensation.
			Field of Posterior Cutaneous of the Hand.	Field of the Terminal Cutaneous Branches.			
				Hypothenar Area.	Involved Digits.		
266. R.J.N. ..	724	214	P1; T0; D0; T°1	P4; T0; D0; T°2	P4; T0; D0; T°2	Some tenderness.	Defective.
328. G.I.T. ..	177	188	P3–4; T3; D0; T°2–3	P4; T4; D0; T°3	P2–3; T2–3; D0; T°2–3	Tender.	Defective.
139. E.D.B. ..	Few hours.	252	P3; T4; D0; T°2	P4; T3; D0; T°2	P4; T3; D0; T°2	Normal.	Very good.
289. H.E.J. ..	Few hours.	192	P2; T0; D0; T°1		P1; T0; D0; T°0	Dull sensation.	No improvement.
307. J.A.P.B. ..	Few hours.	102	P1; T0; D0; T°1	P2; T0; D0; T°1	P1; T0; D0; T°1	Tender.	No improvement.
337. K.B.C. ..	Few hours.	252		P2; T0; D0; T°1		"Dead" sensation.	No improvement.
290. A.B.R. ..	1	211	P2–3; T2; D0; T°2–3	P2–3; T2; D0; T°2–3	P2–3; T2; D0; T°1	Tender.	No improvement.
105. K.T.F. ..	2	200	P2; T4; D0; T°2	P4; T2–3; D0; T°2	P3; T3; D0; T°2	Normal.	Very good.
325. E.H. ..	5	180	P2; T1; D0; T°1	P2; T1; D0; T°1	P1; T0; D0; T°1	No feeling.	No improvement.
127. D.F.W. ..	56	268	P3; T4; D0; T°1	P4; T1; D0; T°1	P1; T0; D0; T°1	"Dead-hard."	No improvement.
158. A.P. ..	104	237	P2; T3; D0; T°1	P2; T1; D0; T°1	P2; T1; D0; T°1	Pain.	No improvement.
269. C.T.B. ..	277	227	P2; T1; D0; T°2	P4; T2–3; D1; T°3	P4; T2–3; D1; T°3	Tender.	Defective.
76. R.W.L. ..	Few hours.	77	P2–3; T2; D0	P4; T0; D0	P4; T0; D0	Some tenderness.	Defective.
299. J.A.T. ..	Few hours.	102	P1; T0; D0; T°0	P1–2; T0; D0; T°0	P1; T0; D0; T°0	Dull sensation.	No improvement.
75. G.W.S. ..	6	183		P1; T0; D0; T°0		Dead sensation.	No improvement.
207. A.J.S. ..	131	230	P4; T3–4; D1; T°3	P2–3; T1–3; D1; T°3	P2; T1; D0; T°3	"Delayed pressure."	Defective.
38. J.L. ..	191	278	P4; T4; D0; T°3	P4; T3; D0; T°3	P3–4; T0; D0; T°2	Normal.	Defective.
322. O.A.R. ..	227	161	P4; T3–4; D0; T°3	P4; T0; D0; T°2	Little: P4; T0; D0; T°1 Ring; P1–2; T0; D0; T°1	Tender.	Defective.
183. C.P.C. ..	272	221	P4; T4; D0; T°2	P4; T4; D0; T°2	P4; T4; D0; T°2	Normal.	Defective.
277. R.R.V. ..	314	163	P1; T3; D0; T°2	P2; T0; D0; T°2	P1; T0; D0; T°0	"Dead" sensation.	No improvement.
243. J.H.B. ..	Few hours.	223	P4; T3; D0; T°1	P4; T1; D0; T°1	P3–4; T0; D0; T°1	Slight tenderness.	Defective.
100. S.C. ..	320	140		P3; T2–3; D0		Tender.	Defective.
242. J.J. ..	651	154		P1; T0; D0; T°0		"Dead" sensation.	No improvement.
321. F.W.K. ..	873	156		P1; T0; D0; T°0		"Dead" sensation.	No improvement.
182. J.S. ..	960	204	P1; T0; D0; T°0	P2; T0; D0; T°0	P0; T0; D0; T°0	Tender.	No improvement.
246. N.D.S. ..	1012	182		P1; T0; D0; T°0		"Dead" sensation.	No improvement.

being supplied by the median nerve and not to any regeneration of ulnar fibres was confirmed post-operatively when it was noted that excision and suture had failed to influence this movement.

Progress Report.—Voluntary contractions were observed in the *flexor carpi ulnaris* at 30 weeks. Four weeks later the hypothenar mass was tender and the overlying skin was hyperalgesic. A stationary condition was reached at 140 weeks. Details of the motor and sensory recovery are given in Tables X and XI. There were 40 millimetres of wasting in the hand.

CASE 105.—On December 22, 1942, K.T.F. lacerated his right elbow when he fell on broken glass; the wound crossed the inner aspect of the forearm 4·0 centimetres below the medial epicondyle of the humerus. Two days later a completely severed ulnar nerve was repaired 5·0 centimetres below the epicondyle; no details of the operation were available. The *flexor carpi ulnaris* was contracting before and after the operation, indicating that the branches to this muscle left the nerve above the lesion.

Progress Report.—That portion of the *flexor digitorum profundus* controlling the terminal phalanges of the middle, ring and little fingers commenced to contract 16 to 23 weeks after suture; the hypothenar group and the first dorsal interosseous followed at 40 and 65 weeks respectively. Wasting was first assessed by measurement at 80 weeks, when it was present in the hand to the extent of 15 millimetres.

A positive Tinel's sign was elicited 150 millimetres below the lesion at 71 days; 41 days later it was elicited 100 millimetres further distally. The hypothenar mass became tender at 27 weeks. The skin over this area was sensitive to pinprick two weeks later. The stimulus produced a diffuse tingling sensation which could also be elicited, a further two weeks later, by very lightly stroking the area.

A stationary condition had been reached at 200 weeks. The *flexor digitorum profundus* was contracting strongly, improvement being maximal in the section to the little finger. All muscles in the hand were contracting; values for the motor recovery are given in Table X. The *adductor pollicis* was severely paresed and was compensated for by the trick action of the *flexor pollicis longus*. The patient could write, but not as well as before the accident, and the hand tired readily. Despite the residual paresis the hand was a very useful one. The extent and quality of the sensory recovery are given in Table XI.

CASE 127.—On December 8, 1942, D.F.W. lacerated his right elbow when he fell on broken glass. The medial epicondyle of the humerus was splintered and the ulnar nerve severed at that level. The nerve was repaired and bone chips were removed 56 days later; no further details of the operation were available. The wound healed without suppuration, leaving a curved scar behind the epicondyle.

Progress Report.—The *flexor carpi ulnaris* commenced to contract at 19 weeks. All the terminal phalanges could be strongly and fully flexed from the time of the injury, indicating that the median nerve was supplying all components of the *flexor digitorum profundus*. Tinel's sign was elicited 19 centimetres below the suture at 15 weeks and at the base of the hypothenar eminence, 8·0 centimetres further distally, nine weeks later. A few days later the eminence was tender to pressure. The first dorsal interosseous became tender at 29 weeks and at this same time pinprick first elicited a response in the hypothenar region, which took the form of a widely radiating burning sensation.

At 39 weeks the nerve was infiltrated with 2% "Novocain" solution just above the epicondyle. This abolished the deep tenderness in the hand, the hyperalgesia, and voluntary contraction of the *flexor carpi ulnaris*. Three days later the nerve was transposed anterior to the epicondyle, where it was lodged in a groove in the flexor mass. The nerve was of normal texture and only very slightly thickened at the suture line. Stimulation above this level resulted in contractions of the *flexor carpi ulnaris* and in flexion of the ring and little fingers (digital movement indicated that the ulnar half of the *flexor digitorum profundus* was receiving an accessory innervation from the ulnar nerve—see above). In the transposition of the nerve the upper branch to the *flexor carpi ulnaris* was sacrificed.

Two years after repair the *flexor carpi ulnaris* had fully recovered, but there was no other motor recovery. The intrinsic muscles were tender. There was a marked residual griffe deformity of the ring and little fingers. Wasting of the forearm had been reduced from 20 millimetres at 11 weeks to 7·0 millimetres at 109 weeks. Wasting was marked (22 millimetres) in the hand. Three years later all the intrinsic muscles were contracting feebly; the griffe deformity was unchanged. There was no wasting of the forearm, but wasting was present in the hand to the extent of 20 millimetres. Details relating to the extent and quality of the recovery are provided in Tables X and XI.

CASE 139.—On January 18, 1943, E.D.B. was involved in an aircraft accident, when he sustained lacerations to the left wrist from a penetrating object which entered the volar surface and emerged on the dorsum. At the point of entry there was a

curved linear scar crossing the ulnar border of the wrist just above the distal crease and extending to the hand. At the point of exit there was an irregular scar over the dorsum of the wrist. The following structures were severed: (*a*) The ulnar nerve. This was repaired within a few hours. (The records stated that the nerve was sutured with black silk; no further information was provided.) (*b*) The ulnar artery, which was ligated. (*c*) The *flexor carpi ulnaris* and the extensor tendons to the index finger, which were repaired. There was no infection.

Progress Report.—The hypothenar mass was tender to pressure at 24 weeks. This tenderness increased and was very marked four weeks later, when pricking the overlying skin produced a diffuse painful sensation "like an electric tingling". At this time some hypothenar fibres were contracting feebly, but it was not until 51 weeks after repair that the contraction was capable of producing a small range of movements against weak resistance. At this time the first dorsal interosseous commenced to contract.

The patient was last examined at 252 weeks. All muscles were contracting against resistance. Independent movements were well executed by the hypothenar muscles, but only poorly by the interossei and thenar group. Wasting in the hand, which had been maximal at 24 millimetres, was stationary at 15 millimetres. Values for the motor and sensory functions are given in Tables X and XI.

CASE 158.—On April 7, 1943, A.P. lacerated his right elbow when he fell through a glass door. The two arms of a V-shaped wound were directed upwards and outwards from a point on the cubital crease at the inner margin of the biceps tendon. The wound was sutured without exploration and healed by primary intention. When the patient was examined by me four weeks later there was complete loss of function in the ulnar field. Median nerve function was grossly impaired, but subsequently recovered spontaneously.

The ulnar nerve was explored 104 days after the injury. It had been cleanly severed 2·5 centimetres above the medial epicondyle and the nerve ends were joined by a small amount of scar tissue. There was a small soft neuroma on the proximal stump where it entered the scar and a smaller swelling where it emerged below. Stimulation of the nerve above and below the intervening scar tissue failed to elicit a response. Excision of the bulbs and intervening scar tissue and trimming the nerve ends until suitable tissue was revealed increased the gap between them to 4·0 centimetres. The proximal and distal stumps were then mobilized, in the process of which one branch to the *flexor carpi ulnaris* from the lower segment was sacrificed. The nerve ends were joined anterior to the epicondyle and lodged in a groove cut in the surface of the flexor mass. The elbow was fully flexed to permit union without tension. The local conditions were regarded as being quite favourable for repair.

Progress Report.—The *flexor carpi ulnaris* commenced to contract at 18 weeks. When next examined 26 weeks later the ulnar half of the *flexor digitorum profundus* was contracting. Recovery appeared in the hypothenar muscles at 85 weeks and in the first dorsal interosseous at 109 weeks. The hypothenar mass was extremely sensitive to pressure and the overlying skin hyperalgesic at 44 weeks. This deep and superficial tenderness was not present when the patient was examined 18 weeks previously. The patient was last examined at 237 weeks; the state of the motor and sensory functions on that occasion is shown in Tables X and XI.

CASE 182.—On May 17, 1941, J.S. sustained a perforating gunshot wound of the right elbow, which opened the joint, fractured the lower third of the humerus, and completely interrupted conduction in the median and ulnar nerves. There was prolonged infection. The patient was a prisoner of war for two years following the injury, and during this period received no treatment for the nerve lesions. He was first examined by me on July 13, 1943. The entry scar covered the biceps tendon at the elbow crease, and the exit scar the medial epicondyle. Just above the latter a tender bulb could be palpated. Recovery was well advanced in the median field and subsequently reached a condition just short of normal. The only sign of recovery in the ulnar nerve was feeble voluntary contraction of the *flexor carpi ulnaris*. Exploration 960 days after the injury revealed a severed nerve. The proximal stump terminated in a small bulb, which was securely attached to a spur of bone which projected inwards approximately 5·0 centimetres above the epicondyle. The distal stump was located just below the epicondyle; it was much thinner than the proximal and did not carry a bulb. Before mobilization stimulation of the proximal segment resulted in weak contraction of the *flexor carpi ulnaris*; no nerve fibres, however, could be identified crossing the gap. The nerve ends were suitably prepared, the distal stump taken anterior to the epicondyle through a tunnel in the common flexor mass, and union effected without tension by flexing the elbow.

Progress Report.—Recovery appeared in the *flexor carpi ulnaris* at 15 weeks. When the patient was last examined at 204 weeks the *flexor carpi ulnaris* and *flexor digitorum profundus* were contracting strongly, but there was no other motor recovery.

Information relating to the wasting and the motor and sensory recovery is given in Tables X and XI.

CASE 183.—On February 6, 1943, C.P.C. sustained a gunshot wound of the right arm, which left a curved scar across the postero-medial aspect 9·0 centimetres above the tip of the olecranon. The severed ulnar nerve was seen in the wound with a gap of half an inch between the ends. Because of injuries elsewhere the nerve could not be repaired until 272 days after the injury. Exploration revealed that the nerve ends and intervening 5·0 centimetres of scar tissue were adherent to the medial head of triceps. The proximal segment expanded into a firm nodule, which tapered sharply into the scar tissue 7·0 centimetres above the epicondyle. The distal segment became lost just above the epicondyle in the ragged mass of fibrous tissue; there was no sign of any swelling. The calibre of the distal segment was approximately two-thirds that of the proximal. It was paler than, but appeared as vascular as, the proximal segment. The nerve did not respond to stimulation.

The bulb and scarred area were excised and the nerve ends trimmed. Healthy tissue was revealed just above the firm nodule, but trimming distally as far as the epicondyle failed to expose suitable looking tissue. It was considered inadvisable to resect further. Both ends bled freely. The distal segment was mobilized for 8·0 centimetres below the epicondyle and taken anterior to that prominence through a tunnel in the flexor mass. The nerve ends could be approximated without tension only by fully flexing the elbow and wrist. Before and after the operation all sections of the *flexor digitorum profundus* and the first dorsal interosseous were contracting normally. These muscles were innervated solely or predominantly by the median nerve.

Progress Report.—The *flexor carpi ulnaris* commenced to contract at 28 weeks and the hypothenar group 35 weeks later. The hypothenar mass became tender to compression at 32 weeks, when pricking the overlying skin gave an ill-defined, unpleasant sensation which radiated widely. The patient was last examined at 221 weeks. The state of the motor and sensory functions on that occasion is shown in Tables X and XI.

CASE 207.—On August 1, 1943, A.J.S. sustained a shrapnel wound of the right upper arm. This left an oblique scar ten centimetres in length, which crossed the medial aspect of the arm from a point 5·0 centimetres above the medial epicondyle. The field notes stated that the median and ulnar nerves had been severed and that in each case the nerve ends (about one and a half inches apart) had been anchored by linen sutures to fascia; two large vessels (high division of the brachial artery) which had also been severed were ligated. There was complete loss of function in the ulnar and median fields.

When the patient was first examined by me 12 weeks after the injury spontaneous recovery in the median field was so advanced as to exclude the possibility that this nerve had been severed. This spontaneous recovery ultimately proceeded to a state just short of complete restoration of function. Sensation was defective in the field of the medial cutaneous nerve of the forearm and suggested that this nerve might have been mistaken for the median.

The ulnar nerve was explored 131 days after the injury. It appeared and felt normal where it entered a mass of fibrous tissue in the region of the intermuscular septum. The disorganized nerve was traced with difficulty for 2·0 centimetres through this tissue, at the distal end of which it expanded into a large soft swelling separated by a constriction from a firm nodule; below this the nerve was paler but of normal calibre. Stimulation failed to elicit a response. The involved segment was excised and the nerve ends were appropriately trimmed. The distal stump was taken anterior to the epicondyle through a tunnel in the flexor mass. Union was effected without tension, which required almost full flexion of the elbow and wrist.

Progress Report.—The intervals elapsing between repair and the onset of recovery in the various muscles are given in Table X. The hypothenar mass became tender to compression at 20 to 25 weeks; the skin over the proximal third of this zone became acutely sensitive, with over-response, to pinprick at 33 to 42 weeks. There were 2·0 centimetres of forearm wasting 11 weeks after the injury and marked wasting in the hand, which was not measured; 41 weeks later there were 31 millimetres of wasting in the hand.

The extent and quality of the motor and sensory recovery when the patient was last examined at 230 weeks are given in Tables X and XI.

CASE 242.—On April 20, 1941, J.J. sustained a shrapnel wound of the right forearm, with a fracture of the lower end of the ulna and complete interruption of conduction in the ulnar nerve. He was in enemy hands until October, 1943, and his prisoner-of-war notes contained brief data to the effect that (*a*) the wound was grossly infected; (*b*) in 1941, 16 operations were required for drainage of the wounds and removal of sequestra; (*c*) the ulnar nerve was sutured in February, 1942; (*d*) the nerve was reexplored, resutured and transposed anterior to the medial epicondyle in February,

1943; (*e*) a bone graft was inserted in the ulna in August, 1943. No details of these procedures were available.

When the patient was first examined by me on January 1, 1944, there were no signs of recovery in the ulnar field. There was a large, irregular, depressed, adherent scar covering the ulnar aspect of the forearm, extending from the ulnar styloid process to a point 12·5 centimetres above this level. Local scarring indicated that the nerve was occupying an unfavourable bed. At the last examination, 154 weeks after the resuture, there had been no recovery.

CASE 243.—J.H.B. Details relating to the injury and repair are provided in the radial nerve suture case records.

Progress Report.—The *flexor carpi ulnaris* and *flexor digitorum profundus* commenced to contract 4 to 20 weeks after repair. At 37 weeks some fibres of the hypothenar group had just commenced to contract, and six weeks later there was evidence of sensory recovery over the base of the hypothenar eminence. At 51 weeks there had been little further improvement and the nerve was explored. It was freed from scar tissue in which it was firmly buried for 3·0 centimetres above the elbow. The nerve was bulbous at the site of union and palpation revealed a firmness suggestive of patchy intraneural fibrosis. Stimulation resulted in strong contraction of the *flexor carpi ulnaris* and *flexor digitorum profundus* and weak contraction of the hypothenar muscles. The nerve was transposed anterior to the epicondyle; to effect this the first branch to the *flexor carpi ulnaris* was sacrificed.

At 55 weeks feeble contractions were observed in the first dorsal interosseous muscle and sensation had shown further improvement. At 108 weeks the nerve was reexplored in an attempt to correct local tenderness at the site of injury. Stimulation resulted in good contraction of all muscles supplied by the nerve. On an attempt to free the ulnar nerve from scar tissue the median nerve was found firmly adherent to it, and since conduction in the latter was normal, it was thought inadvisable to attempt any further neurolysis.

At 223 weeks the condition had been stationary for several months. The extent and quality of the recovery are given in Tables X and XI. Discrete digital movements were severely impaired owing to the paralysis of the long digital extensors and the residual paresis of the intrinsic musculature. Sensory recovery was more advanced than motor.

CASE 246.—On May 31, 1941, N.D.S. sustained a mortar bomb wound involving the inner aspect of the right upper arm and fracturing the shaft of the humerus. The patient was in enemy hands until November 3, 1943. The prisoner-of-war notes were incomplete, but contained the following information: (1) The wound was grossly infected with discharging sinuses and osteitis of the humerus; eight operations were required for the removal of sequestra. (2) Foreign bodies were retained. (3) Lesions of the radial and ulnar nerves were present; the former was treated conservatively, but a reference to the latter inferred that nerve suture would be required at a later date. Examination on November 3, 1943, in an overseas allied hospital revealed (*a*) healed wounds with adherent scarring, (*b*) almost complete restoration of function in the radial nerve, (*c*) the only evidence of conduction in the ulnar nerve was feeble contraction of the *flexor carpi ulnaris*.

The patient was first examined by me on January 24, 1944. At this time the *flexor carpi ulnaris* and *flexor digitorum profundus* were contracting weakly; there was no other recovery. The ulnar nerve was involved 16 centimetres above the medial epicondyle; at this site there was a tender neuroma beneath the wound scar, which was extensive and adherent to the subjacent structures.

The nerve was explored 1,012 days after injury. The proximal segment terminated in a soft neuroma 15 millimetres in diameter. A firm bulb, not quite as large as the neuroma, was located 5·0 centimetres further distally; below this the nerve was of normal dimensions, consistency and colour. The two bulbs were joined by scar tissue which was densely adherent to neighbouring structures. Closer inspection of this intervening tissue under dissecting spectacles revealed some fine connecting strands, which appeared to be composed of nerve fibres. This interpretation was supported by the results of stimulation of the nerve above the lesion, which resulted in feeble contractions of the *flexor carpi ulnaris* and of the ulnar half of the *flexor digitorum profundus* and puckering of the skin over the hypothenar eminence suggestive of contraction of the superficial fibres of the hypothenar group of muscles.

The bulbs and intervening scar tissue were excised and the nerve ends appropriately trimmed. The distal segment was then freed for 20 centimetres preparatory to transposition, after which the cut face, which had previously bled freely, only oozed blood. The condition suggested that the extensive mobilization of the latter may have impaired its blood supply. The distal segment was passed anterior to the epicondyle through a tunnel in the flexor mass. The forearm was almost fully flexed in order to permit union without tension.

Progress Report.—The *flexor carpi ulnaris* commenced to contract at 27 weeks. The extent and quality of the recovery when the patient was last examined at 182 weeks are given in Tables X and XI. Wasting in the hand had increased from 24 to 35 millimetres while the patient had been under observation.

CASE 266.—On April 4, 1942, R.J.N. suffered extensive electrical burns of the inner aspect of his right upper arm which involved the ulnar nerve. The wounds healed with considerable scarring, which subsequently required correction by skin grafting. When the patient was first examined by me 98 weeks after the injury there was a complete lesion of the ulnar nerve with a marked griffe deformity, gross wasting in the ulnar field and many healed burns and ulcers over the little finger. A large tender bulb could be palpated on the ulnar nerve 5·0 centimetres above the medial epicondyle. The nerve was explored 724 days after the injury. The proximal stump was traced into scar tissue 5·0 centimetres above the epicondyle, where it ended in a large, hard bulb. At the epicondyle the calibre of the distal stump was approximately one-half that of the proximal; just above this level it became lost in the scarred area. Stimulation produced no contractions of any muscle and the *flexor carpi ulnaris* did not respond to direct stimulation. The bulb, intervening scarred segment, and as much of the distal stump as possible were then excised. The composition of the presenting nerve ends was such that little, if any, recovery could be expected, but further resection was impracticable. The distal stump was passed through a tunnel in the common flexor muscle origin after sacrificing the upper branch to the *flexor carpi ulnaris*. The nerve ends were approximated with difficulty and under considerable tension with the elbow and wrist fully flexed and the arm by the side.

Progress Report.—Motor recovery appeared simultaneously in the *flexor carpi ulnaris* and *flexor digitorum profundus* at seven weeks. The rapid improvement in these muscles was reflected in the reduction in forearm wasting; at 18 weeks there were only 5·0 millimetres of wasting. The hypothenar mass became tender to pressure and the overlying skin showed signs of recovering sensation at 18 weeks; the deep tenderness has persisted. The patient was last examined at 214 weeks. The griffe deformity had been almost fully corrected, wasting in the hand had been reduced from 25 to 14 millimetres. The extent and quality of the motor and sensory recovery at the last examination are given in Tables X and XI.

CASE 269.—On June 13, 1943, C.T.B. lacerated his right elbow on a broken lampshade at sea. The wound was sutured half an hour after the injury. It became septic, but responded rapidly to treatment. The resultant scar was 4·0 centimetres in length and crossed the ulnar border of the forearm 3·0 centimetres below the medial epicondyle. A complete lesion of the ulnar nerve was recorded 10 days after the injury. When first examined by me 260 days later there was complete loss of function in the ulnar field below the *flexor carpi ulnaris* and *flexor digitorum profundus*. The nerve was explored seven days later. It had been severed 3·0 centimetres below the epicondyle, and approximately 1·0 centimetre of firm, hard, fibrous tissue separated the nerve ends. This scar was circumscribed and no difficulty was experienced in mobilizing the nerve. The proximal stump terminated in a well-defined soft bulb from which a branch passed to the *flexor digitorum profundus*. Above the bulb two branches left the nerve to enter the *flexor carpi ulnaris*. Stimulation of the proximal segment produced brisk contraction of the *flexor carpi ulnaris* and *flexor digitorum profundus* (middle, ring and little fingers). The distal stump commenced in a small swelling; distal to this the nerve was only slightly reduced in calibre as compared with the proximal segment, and from it a branch passed which was not traced to its destination. Stimulation of the distal stump produced no response.

The bulbs and intervening scar tissue were excised. In all, about 4·0 centimetres of tissue were removed before the nerve ends were considered suitable for suture; in the process the branch to the *flexor digitorum profundus* was sacrificed. In order to permit mobilization of the proximal stump, preparatory to transposing it subcutaneously in front of the epicondyle, one branch to the *flexor carpi ulnaris* was severed. The nerve ends were sutured without tension with the elbow fully flexed. After the operation the *flexor carpi ulnaris* and *flexor digitorum profundus* (relevant section) were not contracting.

Progress Report.—The intervals elapsing between the time of suture and the onset of recovery in the different muscles are given in Table X. There was no sensory recovery at 21 weeks. Squeezing the hypothenar mass six weeks later gave rise to a stinging sensation, while pinprick in the overlying skin resulted in an unpleasant tingling sensation which radiated widely over the ulnar half of the hand. When the patient was first examined by me, wasting was marked in the hypothenar and interosseous regions and was present to the extent of 3·5 centimetres. When he was last examined only a trace of wasting could be detected on inspection and the circumference of each hand measured 23·1 centimetres.

The patient was last examined at 227 weeks. The extent and quality of the motor and sensory functions, which were assessed as being very good indeed, are given in Tables X and XI.

CASE 277.—On December 9, 1943, R.R.V. sustained multiple and extensive grenade wounds of the medial and lateral aspects of the left upper arm. Vascular injury necessitated the application of a tourniquet. Examination the following day revealed: (*a*) an extensive wound 10 centimetres in length, extending down the brachial furrow from the axilla; (*b*) severed brachial vessels which were ligated; (*c*) a severed ulnar nerve which was not sutured; (*d*) the median and musculo-cutaneous nerves in continuity. The wounds became infected and poured pus for some time. Local conditions delayed nerve repair until 314 days after the injury. The first dorsal interosseous muscle was contracting before operation; this was attributed to a partial supply from the median nerve.

The proximal stump terminated in a firm bulb, which was separated from the distal segment by 2·0 centimetres of dense scar. The latter segment did not carry a bulb and was only slightly reduced in diameter. There was no response to stimulation. Excision of the scar and bulb and appropriate trimming of the nerve ends left a gap of 5·0 centimetres. In preparing the nerve ends it was noted that it was necessary to sacrifice more of the proximal segment before healthy tissue was exposed. The distal segment was mobilized for approximately 20 centimetres, after which the cut surface continued to ooze blood, though not with the rapidity observed before mobilization. The nerve was transposed subcutaneously in front of the epicondyle and union effected 14 centimetres above that bony point. The elbow was fully flexed in order to avoid tension.

Progress Report.—Voluntary contractions were observed in the *flexor carpi ulnaris* and *flexor digitorum profundus* at 26 weeks; 35 weeks later the hypothenar group were contracting. The hypothenar mass became tender to pressure at 11 weeks. The ulnar cutaneous field was insensitive at 41 weeks; when next examined at 51 weeks pinprick elicited a painful response from the base of the hypothenar region.

The patient was last examined at 163 weeks. All muscles were contracting but were capable of producing only feeble voluntary movements. The range of activity was restricted by extraneural changes and the mechanical obstruction to function prevented a true assessment of motor recovery. Before exploration there were 4·0 centimetres of wasting in the forearm and 3·0 centimetres in the hand; when last examined the wasting was unchanged. The extent and quality of the final recovery are given in Tables X and XI.

CASE 289.—On April 13, 1944, H.E.J. lacerated his left elbow. The joint was breached and the triceps tendon and ulnar nerve were severed just above the medial epicondyle of the humerus. The tendon and nerve were repaired immediately following the injury. No further details of the operation were available. There was no infection. The scar, approximately 10 centimetres long, extended upwards and outwards across the dorsum of the arm from the medial epicondyle of the humerus. The first dorsal interosseous received a partial supply from the median nerve. Eleven weeks after repair the nerve was transposed anterior to the epicondyle. The suture line was firmly fixed in scar tissue just above and behind the epicondyle; stimulation gave no response. Dissection revealed a slightly scarred segment, about one inch in length, which carried two adjacent small lateral swellings. It was decided at that stage not to resect and resuture.

Progress Report.—Voluntary contractions were observed in the *flexor carpi ulnaris* and in the *flexor digitorum profundus* at 16 weeks. Fifty-five weeks later these muscles were contracting strongly; at this time no other muscles were contracting and there had been no sensory recovery. Improvement in the proximal muscles was reflected in the reduction in the wasting of the forearm. There were 28 millimetres of wasting at 14 weeks; at 71 weeks this had been reduced to 8·0 millimetres. Over this period the wasting of the hand had remained stationary at 3·0 centimetres.

The nerve was reexplored at 71 weeks. A fusiform bulb had formed at the site of union. Stimulation above the bulb resulted in strong contractions of the *flexor carpi ulnaris* and strong flexion of the little, ring and middle fingers and slight flexion of the index finger; hypothenar fibres were observed to contract. After the nerve had been stimulated a dozen times the power of contraction of these muscles diminished considerably, while stimulation of the median nerve continued to give rapid and powerful contraction of the muscles (including the first dorsal interosseous) supplied by it. This stimulation was carried out while the tourniquet was applied. The nerve was not disturbed and the wound closed. Function in the ulnar field was unchanged one month later.

The patient was last examined at 192 weeks. The state of motor and sensory function on this occasion and the extent of the residual wasting are given in Tables X and XI.

CASE 290.—On April 3, 1944, A.B.R. was involved in an automobile accident in which he sustained a lacerated right elbow. The ulnar nerve was severed in the epicondylar groove of the humerus and was sutured about 24 hours later. The nerve ends were easily found and united. There was no infection. The nerve was transposed in front of the epicondyle and lodged in a furrow cut in the flexor mass, 571 days after the injury. At operation a large soft bulb was revealed at the site of repair. This was adherent to scar tissue, from which it was easily freed. Stimulation above and below the bulb gave good contraction of the *flexor carpi ulnaris*, *flexor digitorum profundus* (ring and little fingers) and weak contraction of the *abductor digiti quinti*.

Progress Report.—The *flexor carpi ulnaris* and *flexor digitorum profundus* commenced to contract at 17 weeks, the *abductor digiti quinti* at 81 weeks and the first dorsal interosseous at 102 weeks. At 10 weeks the circumference of both hands measured 20·5 centimetres, though wasting was just visible to inspection. Seven weeks elapsed before measurements were again taken, and on this occasion there were 1·2 centimetres of wasting on the involved side; this rapidly increased to 2·0 centimetres. Reduction in the wasting was evident soon after the onset of recovery in the hypothenar muscles; thirteen weeks after this event the wasting had been reduced to 1·0 centimetre.

The distances at which Tinel's sign was elicited (measured from the lesion) and the times from the date of suture were 15 millimetres at 33 days, 110 millimetres at 71 days, 290 millimetres at 163 days, and 320 millimetres at 199 days. The hypothenar mass became tender to compression at 23 weeks and the first web space 33 weeks later. The cutaneous field was insensitive at 41 weeks; when next examined five weeks later pinprick over the hypothenar area gave rise to a radiating, excruciatingly painful sensation.

When last examined at 211 weeks, motor and sensory function had been stationary for several months. The extent and quality of the recovery are given in Tables X and XI.

CASE 299.—On July 27, 1942, J.A.T. sustained a gunshot wound of the left wrist severing the ulnar nerve and artery just above the distal wrist crease. The artery was ligated and the nerve repaired within a few hours of the injury. No further details were available. The wound healed without becoming infected and left a scar 9·0 millimetres long, which extended proximally from the pisiform.

When first examined by the writer at 102 weeks, the hypothenar, interosseous and *adductor pollicis* muscles were contracting. The first dorsal interosseous could fully abduct the index finger against resistance; the remaining muscles were contracting only feebly. There had been no significant recovery of cutaneous sensation; pinprick over the hypothenar region was interpreted as a tap. The final assessment of motor and sensory function is given in Tables X and XI.

CASE 307.—On April 29, 1944, J.A.P.B. thrust his right forearm through a pane of glass and lacerated his wrist. The wound, which was irregular and transversely directed across the forearm just above the wrist, was explored within a few hours and revealed (*a*) severed ulnar nerve and the dorsal cutaneous nerve of the hand (these were repaired); (*b*) a severed ulnar artery, which was ligated; (*c*) severed tendons of the *flexor carpi ulnaris*, the *flexor digitorum sublimis* to the third, fourth and fifth fingers, and the *flexor digitorum profundus* to the fourth and fifth fingers; these were sutured. The wound healed by primary intention. A large palpable neuroma developed at the site of union.

Progress Report.—The ulnar field was insensitive at 10 weeks. Ten weeks later the hypothenar area was tender to pressure, and pricking the overlying skin and the volar surface of the proximal phalanx of the little finger produced a diffuse tingling sensation. Light stroking evoked a similar response, which was, however, less distinct. Pinprick along the ulnar side of the ring finger gave rise to a non-localizable painful sensation. There was no motor recovery at 31 weeks, but when next examined at 56 weeks the hypothenar muscles were contracting. The patient was last examined at 108 weeks, when the extent and quality of the recovery were as given in Tables X and XI.

CASE 321.—On July 22, 1942, F.W.K. sustained a shrapnel wound of the inner aspect of the left arm, resulting in (*a*) a grossly comminuted fracture of the lower third of the humerus, (*b*) complete interruption of conduction in the ulnar nerve, (*c*) extensive destruction of the medial head of triceps. The wound was infected and discharged for eight months. When first examined by me, 118 weeks after the injury, there were no signs of regeneration. A depressed, adherent, elongated scar, 5·0 centimetres in width, extended upwards from the medial epicondyle for 12 centimetres; at the top end of this a bulb could be palpated on the ulnar nerve. Exploration was not carried out until 47 days later. The proximal segment ended in a bulb at the upper end of the scar. The distal segment terminated abruptly, and without any expansion, in scar tissue 4·0 centimetres above the epicondyle. The bulb and intervening scar tissue were excised and after appropriate treatment of the nerve ends there was a gap of 7·0

centimetres between them. The distal segment was taken anterior to the epicondyle through a tunnel in the flexor mass and the nerve ends sutured. Even with full flexion of the elbow the suture line was under tension.

Progress Report.—The patient was not examined again until 56 weeks after repair. At this time the *flexor carpi ulnaris* was contracting feebly and the hypothenar mass was very tender to compression. The condition was unchanged six weeks later. At 156 weeks the *flexor carpi ulnaris* was contracting weakly and a flicker of contraction was visible in the hypothenar mass. There was a severe griffe deformity of the ring and little fingers, which was not fully reducible in the latter. There was gross wasting in the ulnar field. Pinprick was recorded as contact over the cutaneous area and there was no appreciation of light touch. The final assessment of motor and sensory function is given in Tables X and XI.

CASE 322.—O.A.R. Details of the injury and operation are provided in the section relating to the median nerve.

Progress Report.—The *flexor carpi ulnaris* commenced to contract 117 to 128 weeks after repair. When the patient was last examined at 161 weeks there had been no further motor recovery. Signs of sensory recovery were evident over the hypothenar area at 24 weeks; they had not been present seven weeks earlier. Sensory recovery was still proceeding when the patient was last examined; the assessment of sensation on that occasion is given in Table X.

CASE 325.—On October 5, 1944, E.H. sustained a V-shaped laceration of the ulnar border of the right forearm. The apex of the wound, from which the arms diverged upwards, was situated approximately 5·0 centimetres above the ulnar styloid process. The *flexor carpi ulnaris* and the ulnar nerve and vessels were severed and the medial half of the *flexor digitorum profundus* was severely lacerated. The nerve was not repaired until five days later. No further information was available. There was no wound infection. A palpable, tender, fusiform neuroma developed at the suture line.

Progress Report.—Contractions were observed in the hypothenar mass at 40 weeks and in the first dorsal interosseous 14 weeks later. When the patient was last examined at 180 weeks the condition had been stationary for four months. The extent and quality of the sensory and motor recovery are given in Tables X and XI.

CASE 328.—On September 6, 1944, G.I.T. was involved in an automobile accident in which she sustained a fracture of the mid-shaft of both bones of the left forearm. The fractures were reduced the following day. Traction reduction was required three weeks later and was applied through the olecranon and the lower end of the radius and ulna. The pins were removed six weeks after being applied. Twenty-six days later the history reported "ulnar nerve palsy which has (?) been present since the day of the accident". When the patient was first examined by me 15 weeks after the injury there was complete interruption of conduction in the ulnar nerve at the mid-forearm level, with 3·0 centimetres of wasting in the hand. A small healed scar at the site of the fracture was barely visible. Bony union was well advanced but not complete; alignment of the radius and ulna was excellent.

The nerve was explored 177 days after the injury. It was in continuity with a small firm bulb which was adherent to scar in the *flexor digitorum profundus* at the level of the fracture of the ulna. This scar was underlying and continuous with the scar in the skin. Distal to the bulb the nerve was slightly reduced in calibre. The bulb and about 2·0 centimetres of the nerve trunk were excised before tissue which was favourable for suture was exposed. The proximal segment was transposed to the front of the elbow under the common flexor origin and the nerve repaired, approximately 15 centimetres above the distal wrist crease. There was no tension with the elbow at right angles. The nerve was not stimulated during the operation.

Progress Report.—The hypothenar mass became extremely tender and the overlying skin hyperalgesic 12 to 20 weeks after repair. Feeble contraction of the hypothenar muscle mass on attempted flexion of the little finger was first possible at 32 weeks; the first dorsal interosseous commenced to contract 10 weeks later.

When the patient was last examined at 188 weeks, motor and sensory function were still improving. The extent and quality of the recovery at that time are given in Tables X and XI.

CASE 337.—K.B.C. Details of the injury, operation and course of recovery are given in the section relating to the median nerve injuries. The final assessment of motor and sensory recovery is given in Tables X and XI.

Ulnar Nerve Suture: Comments.

1. The end result was classed as good in six patients (Cases 38, 105, 139, 183, 207, 269), fair in five (Cases 76, 158, 243, 290, 328) and poor or negligible in 15. Of the 11 nerves showing good or fair recovery in the hand, five were

repaired immediately following the injury, while in six repair was delayed for periods ranging from four to nine months. Three of the latter group were gunshot injuries in which some stretching of the nerve must have occurred post-operatively when the flexed limb was gradually extended; infection, however, was not a complicating factor. The evidence demonstrates that substantial delays in repair are not incompatible with successful recoveries.

In the group showing poor or negligible recovery six nerves were repaired immediately or within a week of injury, one was repaired after a delay of two months, and eight after periods ranging from eight months to three years. The poor recovery following delayed repair cannot be attributed solely to the delay, since the end result was equally bad in some cases of immediate suture while other factors were operating to affect adversely the end result. Thus a concomitant bone injury and prolonged infection, necessitating a delay before repair can be undertaken, usually indicate a more severe nerve injury which induces proportionately more severe retrograde neuronal changes. Furthermore, the length of nerve destroyed or requiring resection was considerable in some cases, while in others preparation of the nerve ends was unavoidably incomplete and union could be effected only under tension. An analysis of the end results suggests that, providing the local conditions are favourable for repair, good results can follow repair which has been delayed for periods up to nine months.

TABLE XII.

Site.	Laceration.		Gunshot Wound.	
	Good or Fair Recovery.	Poor Result or Failure.	Good or Fair Recovery.	Poor Result or Failure.
At and above the elbow ..	3	3	3	6
Proximal half of the forearm	2	—	1	1
Distal half of the forearm and wrist	1	3	1	2
Number of cases	6	6	5	9

2. The distribution in the laceration and gunshot groups of the good or fair recoveries and the poor results or failures is given in Table XII.

In general, cases of repair following laceration severance fared better than those in which a missile was responsible for the injury. Particularly was this so when the lesion was situated at or above the elbow. The reasons for this have been discussed in a previous section ("Median Nerve Suture: Comments").

The high incidence of failure after laceration severance at the wrist is in contrast to the good end result in the corresponding group of the median nerve series. The following explanation probably accounts for the difference. Whereas 94% of the median fibres at the wrist are cutaneous and 4% are for the thenar muscles, the cross-sectional areas devoted to the cutaneous sensory and motor components of the ulnar nerve are approximately 56% and 44% respectively. Furthermore, as in the median nerve, the funicular pattern is one of many funiculi separated by much connective tissue (Sunderland and Bradley). Consequently after repair of the ulnar nerve at the wrist there is a greater risk of the erroneous cross-shunting of regenerating fibres and of their escape into the interfunicular tissues of the distal stump. This is particularly likely to occur when the funicular patterns of the nerve ends do not correspond.

3. The times at which motor and sensory function were observed to return are given in Table XIII. The cases have been listed according to the quality of the end result, the level of the repair and the duration of the interval between injury and repair. An analysis of the data in this table provides the following information.

(*a*) The times (in months) at which function can be expected to return in the proximal and hypothenar muscles and in the skin covering the hypothenar area are summarized in Table XIV. Values given by Stopford (1920, excluding very exceptional cases), Stookey and Scarff (1943), and Björkesten (1947) for the onset of recovery are included for comparison; the conditions

TABLE XIII.

Information relating to the Onset of Recovery following Repair of the Ulnar Nerve.

Case and Level of Repair.	Causative Injury.	Interval, in Days, between Injury and Repair.	Grade of Recovery.	Onset of Recovery in Weeks.		
				Motor.		Cutaneous Sensation.
				Proximal Muscles.	Hypothenar Muscles.	
At and above the elbow:						
289	Laceration.	Few hours.	Poor.	16	71	—
243	Gunshot wound.[1]	Few hours.	Fair.	4 to 20	37	37 to 43
290	Laceration.	1	Fair.	17	81	41 to 46
105	Laceration.	2	Good.	16 to 23	40	27 to 29
127	Laceration.	56	Poor.	19	104 to 268	29
158	Laceration.	104	Fair.	18	85	18 to 44
207	Gunshot wound.	131	Good.	14	67	33 to 42
322	Gunshot wound.	227	Poor.	117 to 128	—	17 to 24
183	Gunshot wound.	272	Good.	28	63	32
277	Gunshot wound.	314	Poor.	26	61	41 to 51
100	Gunshot wound.[1]	320	Poor.	30	67	34
266	Burn.	724	Poor.	7	77 to 97	18
182	Gunshot wound.[1]	960	Poor.	15	—	—
246	Gunshot wound.[1]	1012	Poor.	27	68	—
Proximal half of the forearm:						
76	Gunshot wound.	Few hours.	Fair.	—	40 to 77	7 to 21
328	Laceration.	177	Fair.	—	32	12 to 20
269	Laceration.	277	Good.	18	46	27
Distal half of forearm and wrist:						
139	Laceration.	Few hours.	Good.	—	28	28
307	Laceration.	Few hours.	Poor.	—	31 to 56	10 to 20
325	Laceration.	5	Poor.	—	40	—
38	Gunshot wound.	191	Good.	—	17	15

[1] Concomitant bone injury.

obtaining in the individual cases from which their data were derived were not given by them.

(*b*) The early onset of recovery is no guarantee that regeneration will proceed satisfactorily and culminate in a successful result, while successful results were sometimes observed to follow the late onset of recovery. This is in agreement with observations made on the cases of radial and median nerve repair. The findings emphasize the importance of allowing sufficient time for the appearance of returning function before contemplating resuture.

(*c*) Delays in repair of up to nine months do not appear to influence the time of onset of returning function.

(*d*) Signs of cutaneous sensory recovery usually appear over the hypothenar eminence before the onset of voluntary contraction in the subjacent muscles. The reasons for this have already been discussed ("Median Nerve Suture: Comments").

(*e*) There was no constant relationship between variations in the onset and course of recovery and the level and nature of the injury and the time of repair, which indicates that there were other variables influencing the regenerative process.

(*f*) Among the cases in which the patients fared badly there were instances, both after early and delayed repair (more than two years after injury in two cases), when function reappeared at about the same time as it did in those cases which progressed to a good recovery. Why did regeneration fail to progress satisfactorily after signs of returning function became evident within the period recorded for cases in which a good recovery ensued? Presumably it is due to a deficiency in the regenerative process which limits the number of axons reaching appropriate end organs and the number of peripheral units that are restored to full activity on reinnervation. This is best accounted for on the basis of:

(i) Retrograde neuronal degeneration.

(ii) The loss of regenerating axons at the suture line and into interfunicular spaces and down functionally unrelated endoneurial tubes. This loss is increased by: (*a*) dissimilarity in the cross-sectional area of the nerve ends consequent on denervation shrinkage of the distal stump; (*b*) dissimilarity in the funicular patterns of the nerve ends which increases with the length of nerve destroyed and resected; (*c*) denervation shrinkage of the endoneurial tubes and the morphological changes occurring in them, which restrict the entry and subsequent descent and maturation of the regenerating axons; (*d*) scarring at the suture line.

(iii) The development of irreversible changes in the end organ, which limits its capacity to function efficiently on reinnervation.

Though factors (ii) (*a*), (ii) (*c*) and (iii) may be held responsible

TABLE XIV.

Ulnar Nerve: Information Relating to the Interval, in Months, Elapsing between Repair and the Onset of Recovery.

Level of Repair.	Onset of Voluntary Contractions.						Onset of Sensory Recovery.		Stookey and Scarff. Nature of Recovery Not Given.
	Proximal Muscles.			Hypothenar Muscles.					
	Stopford.	Björkesten.	This Inquiry.	Stopford.	Björkesten.	This Inquiry.	Stopford.	This Inquiry.	
Proximal half of the upper arm ..		Av. 9·5							15 to 16[1]; 22[2]
Distal half of the upper arm and elbow.	3 to 6	Av. 8·8	3 to 7			10 to 20		11	10 to 12[1]; 16[2]
Proximal half of the forearm ..								Evident in one case at 18 weeks.	
Lower two-thirds of the forearm ..					Av. 10·3	8 to 12		4 to 7	
Wrist						4 to 10	3 to 7	4 to 7	5 to 7[1]; 10[2]

[1] "Under good conditions." [2] "Under poor conditions." Av. = Average.

for the failure of regeneration to progress satisfactorily after delayed repair, they are entirely blameless after immediate or early repair. Furthermore, the evidence presented in this paper suggests that the irreversible changes which develop in the distal stump and end organ as the period of denervation increases do not operate in a significant manner where repair has been delayed for periods not exceeding nine months. From this it may be inferred that the significant factors restricting recovery are (i), ii (*b*) and (ii) (*d*).

4. In the majority of cases there was either no improvement of joint sensibility or this function remained very defective even when cutaneous sensation showed good recovery.

4. *Sciatic Nerve Suture: Case Records.*

CASE 9.—On November 13, 1941, G.A.B. was thrown violently against a telegraph pole when he was involved in a motor cycle accident. Amongst other injuries he sustained complete rupture of the cruciate ligaments of the left knee and complete interruption of conduction in the left lateral popliteal nerve.

In the absence of spontaneous recovery the nerve was explored, 208 days after the injury, in the lower half of the thigh as far distally as the neck of the fibula. The nerve was in continuity, showed no swelling and was not involved in adhesions. Over the central 5·0 centimetres of its exposed length, however, it was thinned and firmer than normal. Stimulation above and below this zone produced no response. The thinned portion of the nerve was excised. During excision the common trunk of the sural communicating and the lateral cutaneous nerve of the calf were sacrificed. The nerve ends presented funiculi and appeared healthy. They were sutured without tension by flexing the knee 90°.

Progress Report.—The only sign of recovery 45 weeks after repair was a positive Tinel's sign just below the neck of the fibula. The *tibialis anterior* and peronei commenced to contract at 78 weeks. At 100 weeks the *tibialis anterior* could lift the foot against gravity and resistance, while the peronei stood out prominently to evert the foot through half the normal range against gravity; the extensors of the toes were not contracting. In the cutaneous field pinprick and light stroking resulted in a tingling sensation which radiated widely.

When the patient was last examined at 284 weeks the condition in the lateral popliteal field was as follows. The foot, which at rest was held slightly inverted, could be everted (peronei) and elevated (*tibialis anterior*) against gravity and weak resistance. The range of execution of the former movement was two-thirds normal and of the latter one-half normal. The foot, however, could be almost fully elevated against gravity and the patient was walking without a limp and without a mechanical aid. The long extensors of the toes were contracting feebly without producing any movement. The circumference of the legs, measured 29 centimetres above the fibular malleolus, showed 42 millimetres of wasting. The area of disturbed sensation was the same as that charted following repair, though within this area sensation had improved considerably. The patient could readily and easily distinguish between the application of the head and point of the pin. Pinprick elicited a sensation described as an "electrical feeling or tingling" which, though sometimes radiating over an area approximately 20 millimetres in diameter, was correctly localized; occasionally at high thresholds there was some false reference. Light and gentle stimulation of the hairs and light touch applied directly to the skin elicited a sensation which could be localized, but which was not nearly as distinctly felt as on the normal side. The residual sensory defect was maximal in front of the ankle. The final assessments of motor and sensory function are given in Tables XVI and XVII.

CASE 62.—On July 1, 1941, B.D. sustained a perforating shrapnel wound of the right thigh. At the point of entry there was a vertical linear scar, 5·0 centimetres in length, commencing 5·0 centimetres above the head of the fibula. The exit was on the postero-medial aspect of the thigh, 18 centimetres above the medial femoral epicondyle. The wound was not infected. No details with reference to the nerve lesion were available. When the patient was first seen by me 62 weeks after the injury there was a complete lesion of the lateral popliteal division of the sciatic nerve. Exploration of the nerve was delayed at the request of the patient. It was performed 571 days after the injury.

The sciatic nerve had not divided into its two divisions at the level of the femoral epicondyles and, owing to the absence of any dense scar tissue, was easily isolated. The lateral division had been cleanly severed just above this level and a gap of approximately one centimetre separated the ends. There was a small proximal neuroma which tailed off distally into a fine fibrous strand which did not reach the distal stump but fused

firmly but superficially with the lateral margin of the medial division. There was no bulb on the distal stump. Both stumps were firmer than the adjacent normal division; palpation, however, suggested that there was little intraneural fibrosis. Stimulation above and below the lesion failed to elicit a response. After appropriate trimming of the stumps a gap of 5·0 centimetres was left between them; this was closed by suturing without tension with the knee partly flexed.

Progress Report.—Recovery appeared in the *tibialis anterior* 45 to 51 weeks after repair. Tinel's sign was elicited at the neck of the fibula at 21 weeks, and 47 weeks later percussion and light stroking in the area between the head and malleolus of the fibula resulted in a widespread unpleasant tingling sensation. When last examined at 254 weeks the *tibialis anterior* could fully dorsiflex the foot with gravity eliminated and the peronei could produce a few degrees of eversion. The remaining muscles were contracting but were unable to execute movement. There were considerable wasting and little sensory recovery. The final assessments of motor and sensory function are given in Tables XVI and XVII.

CASE 94.—On October 26, 1942, M.G. sustained a perforating bullet wound of the right thigh, which resulted in complete loss of function in the sciatic field. At the point of entry there was a vertical linear scar centred 17·5 centimetres directly above the lateral femoral epicondyle. At the point of exit there was a small, irregular, circular scar 2·0 centimetres directly above the medial femoral epicondyle. X-ray examination revealed retained foreign bodies. The wounds were mildly infected.

When first examined by me 81 days after the injury the hamstrings could fully flex the knee against strong resistance. A flicker of knee flexion had been reported at nine days (the level of the lesion was below the source

TABLE XV.

Sciatic Nerve: Information Relating to the Injury and Conditions of Repair.

The cases have been grouped according to the causative injury and the duration of the interval elapsing between injury and repair.

Case and Nature of the Causative Injury.	Age.	Level of Suture in Centimetres.	Interval in Days between Injury and Suture.	Infection.	Scar.	Length of Nerve Destroyed.	Tension.[1]	Treatment of Nerve Ends.	Suture Material.
Laceration:									
335. N.W.	11	Popliteal fossa.	7 hours	Nil.	Nil.	Negligible.	No.	Adequate.	Catgut and silk.
Closed injury:									
9. G.A.B.	19	Lower third thigh.	208	Nil.	Nil.	Considerable.	No.	Adequate.	Silk.
Gunshot wound:									
334. —.D.		Buttock.	164	Nil.	Nil.	Considerable.	Unknown.	Unknown.	
155. F.J.H.	24	Upper third leg.	280	Nil.	Nil.	Intermediate.	No.	Adequate.	
336. E.V.J.	29	15·0 above M.F.E.	349	Nil.	S.	Considerable.	No.	Adequate.	Silk.
62. B.D.	25	10·0 above M.F.E.	571	Nil.	Nil.	Considerable.	No.	Adequate.	Tantalum with a tantalum wrap.
94. M.G.	25	20·0 above M.F.E.	830	I.	Nil.	Considerable.	No.	Adequate.	Silk.
Gunshot wound plus bone injury:									
122. P.H.	23	Buttock. 36·0 above M.F.E.	249	I.	Nil.	Considerable.	No.	Adequate.	Silk.
137. C.G.W.	34	20·0 above M.F.E.	627	I.	S.	Considerable.	Yes.	Inadequate.	Silk.

Length of nerve destroyed: 1 to 4 mm.=neglible; 5 to 10 mm.=small; 11 to 30 mm.=intermediate; 30+ mm.=considerable. M.F.E.=medial femoral epicondyle; I. and S.=significant infection and scarring respectively.

[1] Tension after mobilization and posturing the limb.

of the superior branches to these muscles). The outer and posterior aspect of the leg and the sole were hyperalgesic. The case was treated as one in which the nerve was recovering spontaneously.

One hundred and seventeen weeks after the injury the calf muscles and *tibialis posterior* were contracting strongly, the peronei, *tibialis anterior* and long extensors of the toes weakly, while the remaining muscles were still paralysed. Light touch was appreciated over the sole, which was acutely sensitive to pinprick, though the sensation elicited did not radiate widely and was localized. The outer aspect of the leg was hyperalgesic and insensitive to light touch. The trophic condition of the foot was excellent and the patient was walking well with a mechanical aid.

The nerve was explored 11 days later. The projectile had notched the anterior third of both popliteal divisions 20 centimetres above the medial epicondyle. The separated stumps were joined by scar tissue; only the proximal end of the medial division carried a bulb. The bulb was excised, the nerve ends suitably trimmed and the intervening scar tissue removed. A gap of about 3·0 to 4·0 centimetres then separated the nerve ends and union was effected without tension by fully flexing the knee. The nerves were not stimulated during the operation.

Progress Report.—Following the operation there was complete loss of function in the lateral popliteal field, while the condition of the medial popliteal field remained unchanged.

Flexion of the second and third toes was observed at 15 weeks, but whether this could be attributed to the suture was doubtful. The subsequent improvement in sensation over the sole and in the power of the calf muscles and *tibialis posterior* could not be attributed to the suture.

At 109 weeks the only improvement in the lateral popliteal field was (*a*) feeble contraction of the *tibialis anterior*, which had been present for 19 weeks, and (*b*) recovery of superficial pain sensibility over the entire cutaneous field. This recovery could have been due to a restoration of the condition present prior to the operation, which was dependent on the spontaneous recovery of fibres in continuity. The late onset of motor and sensory recovery, however, supported the belief that some regeneration of severed and sutured fibres had occurred. The extent and quality of the recovery present in the lateral popliteal field at 177 weeks are given in Tables XVI and XVII. The condition had been stationary for several months. None of the recovery in the medial popliteal field could be attributed to the repair. How much of that observed in the lateral field could be attributed to the suture is uncertain, but the course of regeneration suggested that most of it was due to the repair.

CASE 122.—On December 28, 1942, P.H. sustained a perforating bullet wound of the left buttock, which resulted in a comminuted fracture of the head and neck of the femur and acetabulum. The entry scar marked the site of a small circular perforation just to the right of the coccyx. Exit and wound *débridement* scar was a long linear scar transversely directed along the gluteal fold of the buttock. Wound *débridement* about 19 hours after the injury revealed a severed sciatic nerve beneath the *gluteus maximus*. The operation notes reported:

> Finally both ends of the sciatic nerve located. The distal end was very ragged. The upper end had retracted up about an inch. Loose mattress suture of linen thread in nerve. When tied there was a gap of one inch.

The wound became infected, and this, together with treatment of the bone injury, delayed nerve repair until 249 days after the injury. The medial hamstrings commenced to contract eight weeks after the injury, but at the time of the operation the knee could be only feebly flexed with gravity eliminated. There were no other signs of recovery.

The nerve was exposed beneath the *gluteus maximus*. The proximal stump terminated, just below the level of the ischial spine, in a large succulent bulb. This was attached by fibrous tissue to the distal stump, which felt normal. There was little surrounding scar tissue. Branches to the medial hamstrings passed from the proximal stump just above the bulb. One branch, arising from the lower end of the bulb and passing medially, was divided; stimulation of this branch did not produce a response and its destination was uncertain. There was no distal bulb and in the operation field no branches were observed leaving the distal stump. The bulb was excised and about 10 millimetres of the proximal stump were trimmed away before healthy bundles were revealed. Favourable tissue was exposed 6·0 millimetres from the extremity of the distal stump. The intervening tissue was removed. By fully flexing the knee it was possible to unite the nerve ends without tension.

Progress Report.—The biceps commenced to contract at 18 weeks and the gastrocnemius between 27 and 39 weeks later. At 58 weeks cutaneous sensation showed signs of recovery in the form of a burning, tingling response to pinprick applied in the area about and below the head of the fibula. Prior to this, successive examinations had revealed a progressively descending Tinel's sign, which was finally elicited from the sole and dorsum of the foot.

TABLE XVI.

Sciatic Nerve: Progress, Extent and Quality of Motor Recovery.
The cases have been listed as in Table X.

Case.	Interval, in Days, between Injury and Suture.	Interval, in Weeks, between Repair and Last Examination.	Return of Voluntary Contraction in Weeks Dating from Time of Repair.							Extent and Quality of Recovery in the Foot. The range and power of movements have been expressed as a percentage of those on the normal side. The value for the range precedes that for the power.						Residual Wasting of the Leg, in Millimetres.
			Biceps.	Gastrocnemius and Soleus.	*Tibialis posterior.*	*Flexor digitorum* and *flexor hallucis longus.*	*Tibialis anterior.*	Peroneal.	*Extensor digitorum* and *extensor hallucis longus.*	Eversion of Foot.	Extension of Foot.	Extension of Toes.	Flexion of Foot.	*Tibialis posterior.*	Flexion of Toes.	
335. N.W. ..	7 hours	131					30–37	30–37	41–46	Full/60	Full/60	Full/50				6
9. G.A.B. ..	208	284					78	78	100–284	66/G,[1] weak	50/G,[1] weak	0/0[2]				42
334. —.D. ..	164	65		N.R.	N.R.	N.R.	N.R.	N.R.	N.R.							
155. F.J.H. ..	280	248		N.I.	20–43	50–59								Strong	Feeble	
336. E.V.J. ..	349	126					4–67	4–67	E.D.L. 74–89 E.H.L. 114–126	Full/8	Full/5	5/0				28
62. B.D. ..	571	254					45–51	53–67	105–127	25/0	Full/0	0/0				37
94. M.G. ..	830	177					90	109–135	N.R.	0/0	Flicker					86
122. P.H. ..	249	266	18	45–57		F.H.L. 231–256	98–116	N.R.	N.R.	0/0	Flicker	0/0	Full/75		Flicker	75
137. C.G.W. ..	627	175		20–33	N.R.	N.R.	N.R.	N.R.	N.R.				20/66[2]			80

N.I. = not involved; N.R. = no recovery; [1]G weak = against gravity and weak resistance; [2] restricted by joint changes; 0/0[2] = the relevant muscles are contracting but not sufficiently strongly to produce movement.

When the patient was last examined at 266 weeks, regeneration was still proceeding. The extent and quality of the recovery at that time are given in Tables XVI and XVII. Œdema of the leg prevented a correct assessment of wasting.

CASE 137.—On October 31, 1942, C.G.W. was involved in a landmine explosion which resulted in a comminuted fracture of the mid-third of the left femur and complete loss of function in the left sciatic field. The wound was situated just inside the mid-line of the dorsum of the thigh, 23 centimetres above the medial femoral epicondyle. Multiple retained foreign bodies were revealed by X-ray examination. Infection and osteomyelitis were severe and prolonged; sinuses were still discharging 70 weeks after the injury. Healing left a large, depressed, adherent scar. The medial hamstrings were contracting when the patient was first examined by me 18 weeks after the injury; signs of recovery in the biceps were present 14 weeks later.

The nerve was explored 627 days after the injury. There was much dense scar tissue in the involved area and the sciatic nerve was bound to neighbouring tissues for a considerable distance. The only response to stimulation above the scarred area was brisk contractions of all the hamstrings when the electrodes were applied to the postero-medial aspect of the nerve. Stimulation below the scarred area failed to produce a response. The nerve was freed with difficulty. When it was traced into the

TABLE XVII.

Sciatic Nerve: Extent and Quality of Recovery of Cutaneous Sensation.
The cases have been listed as in Table X.

Case.	Interval in Days between Injury and Suture.	Interval in Weeks between Repair and Last Examination.	Sole.	Dorsum of Foot.	Outer Aspect of Leg.
335. N.W. ..	7 hours	131		P4; T2–3; T°1–2.	Normal but for some residual defect in temperature discrimination.
9. G.A.B. ..	208	284		P3–4; T3; T°1.	P3–4; T4; T°1.
334. —.D. ..	164	65		P0; T0; T°0.	
155. F.J.H. ..	280	248	P4; T3; T°1.		
336. E.V.J. ..	349	126		P2–3; T1–2; T°1.	P3; T2; T°1.
62. B.D. ..	571	254		P2; T1; T°0.	P2; T1; T°0.
94. M.G. ..	830	177		P1; T0.	P2; T0.
122. P.H. ..	249	266	P2–3; T2; T°1.	P2–3; T2; T°1.	P2–3; T2–3; T°1.
137. C.G.W. ..	627	175	P1–2; T0; T°0.	P4; T3; T°0.	P4–5; T3–4; T°0.

scarred area from above, branches were revealed which supplied the medial hamstrings and biceps. The nerve had been severed just below the origin of these branches and continuity restored by what appeared to be fibrous tissue. The proximal stump was generally swollen; the appearance did not suggest a neuroma. The distal stump carried no bulb and, in comparison with the proximal, was only slightly reduced in diameter; it felt firmer than the proximal. The bifurcation of the nerve was not seen. Six centimetres of scarred tissue and nerve were excised. Funiculi were revealed after trimming away 1·0 centimetre of the proximal stump, which was still in the region of extraneural fibrosis. In view of the prolonged and severe infection and the residual scarring, more extensive and severe intraneural changes might have been expected in the proximal stump. The distal stump, however, showed only a few bundles and much fibrous tissue, but further section distally would have rendered union impossible. With full flexion of the knee the ends were joined under slight tension. Penicillin powder was sprayed in the wound and a tube left *in situ* for further application of the drug.

Progress Report.—The gastrocnemius commenced to contract 20 to 33 weeks after repair. Tinel's sign was elicited 300 millimetres below the lesion at 140 days; 166 days later the sign was elicited 270 millimetres further distally. The extent and quality of motor and sensory recovery at 175 weeks are given in Tables XVI and XVII. The recovery in the sensory field greatly exceeded that occurring in the motor. The colour and nutrition of the limb were good.

CASE 155.—On July 16, 1942, F.J.H. sustained a perforating bullet wound of the left popliteal region. The wound healed without becoming infected. At the point

of entry there was a small circular scar just above and anterior to the head of the fibula. At the point of exit there was a large oval scar over the popliteal fossa. There was no note of a nerve lesion in the records. When the patient was first referred to me 38 weeks after the injury there was a complete lesion of the tibial nerve just below the origin of branches to the calf muscles. The nerve was explored 14 days later. It had been severed at the point where it passed beneath the soleal arch and just below the origin of a group of intact branches to the calf muscles; these were preserved. The proximal stump terminated in a soft neuroma, which was linked by what appeared to be scar tissue with the distal stump. The latter showed no enlargement and felt normal. There was very little surrounding scar tissue. Stimulation of the proximal and distal stumps produced no effect. Trimming revealed favourable tissue for union within 1·0 centimetre of the ends of both stumps. The intervening tissue was then removed and repair effected without tension with the knee at right angles.

Progress Report.—The *tibialis posterior* commenced to contract 20 to 43 weeks and the long flexors of the toes 50 to 59 weeks after repair. During the latter interval cutaneous sensation reappeared. At 248 weeks the *tibialis posterior* and the long flexors of the toes were contracting against resistance; there was no recovery in the intrinsic muscles of the foot. Pinprick was recorded as sharp over the sole with over-response, but sometimes was appreciated as contact only, though this sensation was correctly localized. Light touch was barely perceptible, but when the patient walked over surfaces of a different texture, for example, wood, mats, carpet, linoleum, he was able to distinguish between them by the sensation to which they gave rise; this he had been unable to do previously. On cold linoleum the sensation was much colder on the involved side. The final assessments of motor and sensory function are given in Tables XVI and XVII.

CASE 334.—On February 7, 1945, D. sustained a penetrating bullet wound of the left buttock. This resulted in complete loss of function in the medial popliteal field of the sciatic nerve, which was explored 164 days after the injury. The medial division, which had been severed, was repaired after excision of 4·0 centimetres of "fibrosed neuromatous tissue". No further details of the operation were available. Successive examinations, up to 65 weeks after repair, failed to reveal any signs of recovery.

CASE 335.—At 5 p.m. on June 8, 1945, N.W., aged eleven years, sustained a laceration of the right popliteal fossa which healed leaving an oblique scar, 6·0 centimetres in length, directed downwards and inwards across the fossa. The lateral popliteal nerve was cleanly severed; it was repaired seven hours later. Little trimming of the nerve ends was necessary and the intraneural topography could not have been greatly disturbed.

Progress Report.—Sensory recovery appeared at the proximal extremity of the zone of loss on the outer aspect of the leg at 11 weeks and progressed uninterruptedly. The *tibialis anterior* and the peronei commenced to contract 30 to 37 weeks after repair and at 46 weeks the remaining muscles were contracting. The patient was last examined at 131 weeks. All muscles were contracting strongly and motor function was considered just short of normal. No mechanical aid was required and the boy was playing football and other sports without any disability. There were 6·0 millimetres of residual wasting. Over the dorsum of the foot and along a narrow strip extending 8·0 centimetres above the lateral malleolus, pinprick and light touch were appreciated, but were not quite as distinct as on the normal side; elsewhere sensation was normal. The final assessments of motor and sensory recovery are given in Tables XVI and XVII.

CASE 336.—On May 30, 1945, E.V.J. sustained a penetrating shrapnel wound of the right thigh. Nineteen days later the femoral vessels were ligated and the retained shell fragment removed. At the point of entry there was a small circular scar on the medial side of the thigh 17 centimetres above the medial femoral epicondyle. At the point of exit there was a small irregular scar on the outer aspect of the thigh thirteen centimetres above the lateral femoral epicondyle. No record was available of the state of the sciatic nerve, but in September, 1945, the nerve was explored and neurolysis performed. The nerve was reexplored 349 days after the injury; spontaneous recovery had occurred in the medial popliteal division, but interruption of conduction in the lateral division was still complete. The nerve was surrounded by adhesions at the level of the lesion. These were cleared and the sciatic nerve was exposed over about 20 centimetres of its length. There was a fusiform swelling which involved about 6·0 centimetres of the medial division. Stimulation resulted in contraction in the calf muscles. The lateral division showed two adjacent bulbs, each about 2·0 centimetres in length, which were separated by a constricted zone. Stimulation failed to elicit a response. The two divisions were then separated and the involved segment of the lateral division was excised. A gap of 4·0 centimetres separated the nerve ends after they

had been suitably prepared for union, which was effected with the knee flexed 90°. A sheet of tantalum was then wrapped round each division and secured with two silk ties.

The patient was first examined by me at 67 weeks. The medial popliteal field was normal. Feeble contractions were observed in the peronei and *tibialis anterior*, but no voluntary movements were possible. No other muscles were contracting. Pinprick over the entire cutaneous field resulted in a widespread tingling sensation. Motor and sensory functions have continued to improve uninterruptedly since the patient has been under observation, and when he was last examined at 126 weeks regeneration was still proceeding. The state of motor and sensory function at that time is given in Tables XVI and XVII.

Sciatic and Popliteal Nerve Suture: Comments.

The overall recovery in this group could be classed as good in one case of immediate suture (335) and in two cases of delayed repair (9 and 155). Some useful recovery was recorded in one patient (336) with a delayed repair of the lateral popliteal nerve, while in two cases of delayed repair of the sciatic nerve (122 and 137) there was good recovery in the calf muscles and a useful recovery of sensation in the cutaneous field. There was no or negligible recovery in three cases of delayed repair (62, 94 and 334).

The series is too small and lacks the variety to provide reliable data on many features of the regenerative process in the sciatic field, though there is some evidence to indicate that good recoveries, which are general or confined

TABLE XVIII.

Case.	Causative Injury.	Level of Repair.	Time of Repair.	Onset of Motor Recovery.
335	Laceration.	Popliteal fossa.	7 hours.	30 to 37 weeks.
9	Closed injury.	Junction of the mid and distal third of the thigh.	208 days.	78 weeks.
122	Gunshot wound *plus* bone injury.	Buttock.	249 days.	Biceps: 18 weeks. Gastrocnemius: 45 to 57 weeks.
137	Gunshot wound *plus* bone injury.	Mid-thigh.	627 days.	20 to 33 weeks.

to certain portions of the peripheral field, can follow repairs which have been delayed for seven to twelve months. Information relating to the causative injury, the time of repair and the interval elapsing between repair and the reappearance of function in those cases in which the recovery was good, either throughout the entire peripheral field or in some part of it, are summarized in Table XVIII.

Values quoted by Stopford (1920), the Medical Research Council Report (1920), Stookey and Scarff (1943), and Björkesten (1947) for returning motor function after repair of the sciatic nerve and its popliteal divisions are given in Table XIX. There was no record of the conditions obtaining in the cases from which these data were derived.

V. ON THE EVALUATION OF VARIOUS PROCEDURES, TECHNIQUES AND PRINCIPLES ASSOCIATED WITH NERVE REPAIR.

The extent and quality of the recovery following nerve suture are influenced by such factors as:

1. The extent and severity of the retrograde neuronal reaction and whether or not this proceeds to degeneration.

2. The capacity of the proximal stump to provide regenerating axons which will reinnervate the distal stump, grow until they reestablish continuity with end organs and ultimately maturate to give functionally efficient pathways.

3. The capacity of regenerating axons to multiply in order to compensate for any loss resulting from the failure of some severed fibres to regenerate or from the wasteful escape of others into the interfunicular spaces and down functionally unrelated endoneurial tubes in the distal segment. Prolific axon sprouting may, however, encourage wasteful cross-shunting of axons and prevent others from reaching their old endoneurial tubes.

4. The cross-sectional area and funicular pattern of the opposed nerve ends. Any disparity in size of the two stumps and any dissimilarity in the funicular patterns of the opposed nerve ends will favour the loss of regenerating axons into the interfunicular spaces of the distal stump.

TABLE XIX.

Sciatic Nerve and its Popliteal Divisions: Information Relating to the Interval, in Months, Elapsing between Repair and the Onset of Recovery.

Investigator.	Gastrocnemius.		Peroneï.		*Tibialis anterior.*	
	Sciatic.	Medial Popliteal.	Sciatic.	Lateral Popliteal.	Sciatic.	Lateral Popliteal.
Slopford	5 to 21	5 to 7	15 to 20	4 to 16	6 to 18	5 to 25
Sargent (M.R.C. Report)— Upper third of thigh ..	4 to 11			5	3 to 4	
Military Orthopædic Hospital (M.R.C. Report).	6½ to 39½ Av. 17	6½	3½ to 39½ Av. 19	12 to 16½ Av. 13½	7 to 39½ Av. 20	8½ to 22 Av. 14½
This Inquiry— Buttock .. .. .. Mid-thigh .. .. .. Lower third of thigh ..	11 to 14 5 to 8			7½ to 9 (Case 335) 19 (Case 9)		7½ to 9 (Case 335) 19 (Case 9)
Stookey and Scarff— Upper third of thigh .. Middle third of thigh .. Peroneal: Popliteal fossa Tibial: Popliteal fossa ..	Site of onset of recovery not stated. 12 to 14[1]; 22[2] 10 to 12[1]; 18[2] 10 to 12[1]; 16[2] 10 to 12[1]; 17[2]					
Björkesten— Proximal half of the thigh Distal half of the thigh ..	Av. 11·8 Av. 8·3	Av. 6·5	Site of onset of recovery not stated. Sciatic repair: Av. 14·6. Sciatic repair: Av. 12·0; Lateral popliteal repair: Av. 8·6.			

[1] "Under good conditions." [2] "Under poor conditions." Av. = Average.

5. The cross-shunting of regenerating axons into functionally unrelated endoneurial tubes, which is, in turn, influenced by such factors as the relative number of fibres destined for individual branches and the extent to which they are localized at the level of repair.

6. Tissue reactions at the suture line which may retard or prevent the entry of regenerating axons into the distal stump.

7. The state of the denervated end organ and its capacity to function efficiently when reinnervated.

8. The disturbance of the peripheral pattern occasioned by the erroneous cross-shunting of regenerating axons and the capacity for correcting this by reeducation.

This list could be extended, but it is not the purpose of this paper to provide a detailed discussion of this question. This will be done elsewhere. However, it is important to keep in mind that several factors always combine in any one case to influence the extent and quality of the recovery after suture and that all of these are subject to a wide range of variation from individual to individual, nerve to nerve and, in respect of certain of these factors, from

level to level along the same nerve. For this reason it is necessary, when evaluating a particular procedure or technique associated with repair (for example, rerouting, the relative merits of various suture materials and the usefulness of galvanic stimulation) or when assessing the influence on the end result of a particular variable (for example, sepsis and the interval elapsing between injury and repair) to take into consideration each of the several variables that combine to affect the end result, and not to concentrate solely on the particular factor under review. To date it has not been possible to do this, since we still lack essential information relating to many of these factors, while others, such as the extent and severity of the retrograde reaction, though well recognized, defy assessment. Consequently it is difficult to determine the extent to which each of the participating variables contributes to the residual loss on the completion of regeneration, and since function is never completely restored after suture, we are deprived of a direct method of isolating those factors that do not adversely affect the regenerative process. This deficiency will be remedied only when the following information, based on individual records in large series of repairs, becomes available for statistical analysis: (*a*) precise assessments of the late end results, (*b*) detailed observations covering the several variables operating in each repair. However, the absence of this essential information has not deterred many from assigning to the interpretations of their observations a finality that is quite unwarranted and misleading. Recent literature is replete with examples of a complete disregard for the complexity of the regenerative process. Particularly is this so when the quality of the end result is used as the sole criterion for deciding the optimum time for repair without taking into consideration the other variables which must have contributed to it. In this report frequent reference will be made to the gaps in our knowledge of the variables influencing the extent and quality of recovery and to the limitations which this imposes when attempting an assessment of the influence on recovery of a particular principle, procedure or technique associated with nerve repair.

VI. When Should a Severed Nerve be Repaired?

Lesions that are clinically complete but in continuity should be treated conservatively until adequate time has been allowed for recovery to occur spontaneously. Resection and repair of these injuries should be undertaken only when recovery has failed to appear under these conditions (Sunderland, 1947). This involves greater delays than those usually recommended. The end results of nerve suture are not such as to encourage satisfaction and complacency, and there can be no greater tragedy in peripheral nerve surgery than the excision of an injured segment with end-to-end repair in a nerve that would have recovered spontaneously. In this section, however, the discussion will be confined to a consideration of the stage at which repair should be undertaken in the case of a nerve that is known to have been severed.

An examination of the end results reported in this paper reveals, as do analyses of most other series, that the primary suture and the early and delayed secondary suture groups each provide examples of good recoveries. The data in fact indicate that within reasonable limits after injury (up to at least 11 months) it may be immaterial when the nerve is repaired and suggest that factors other than those related to and dependent on this time interval are responsible for the wide variations in the extent and quality of the recovery in individual cases. Though some of these factors are known, the full range and scope of their influence have yet to be revealed, though investigations

into the anatomy of peripheral nerve trunks continue to add to their number and to emphasize their importance. To date, however, there have been no assessments of end results in which these factors, or at least those that have already been established, have received adequate consideration, nor is the time opportune, for reasons outlined in the previous section, for a consideration of them in this report. However, it is certain that until all the factors affecting the extent and quality of recovery after repair have been revealed and the nature and extent of the influence they exert precisely defined, any attempts to fix the optimum time for repair on the sole basis of the incidence of good recoveries in a particular group of a relatively small series of cases must remain inconclusive. Thus the observation that one or other group shows a higher incidence of good recoveries cannot be accepted as a reliable guide to the optimum time for the repair of severed nerves and lacks significance in the absence of detailed information relating to all the other variables influencing the end result.

It may be taken as axiomatic that a severed nerve should be sutured immediately local conditions are considered favourable for efficient repair. The decision as to when local conditions are to be adjudged favourable, however, invites debate.

There is no doubt concerning the extensive infected wound with gross loss of tissue, which heals slowly and shows extensive residual scarring. In such wounds the severed nerve has rarely been cleanly divided. On the contrary, a segment of the nerve of variable length has usually vanished and the nerve ends are bruised and ragged. There is general agreement that the nerve ends should not be sought, but that if they are visible they should be approximated and fixed by anchoring sutures. By so doing the proximal and distal segments are gradually stretched post-operatively so that end-to-end union can be performed more easily at a later date, when the reaction to infection and trauma has subsided. In other words, repair should never be attempted in an infected field nor in one in which tissue damage from the injury and *débridement* have precipitated reactions which ultimately culminate in extensive scarring. In these cases delayed repair is fortuitously imposed on the surgeon.

The problem is more difficult when the wound is a laceration in which the nerve and neighbouring tissues have been cleanly divided. Attempts have recently been made to determine whether or not primary suture of the nerve is justified even under these conditions (Seddon, 1944; Zachary and Holmes, 1946). These have led to the general conclusion that in these cases it is preferable to perform early secondary suture immediately the local reaction to the injury (no matter how minimal this may be) has subsided. The advocates of this policy advance the following arguments in support of their claims.

On the basis of a comparison of the results of 55 primary sutures with those of a series of early secondary sutures, Zachary and Holmes (1946) concluded that "there is a better prospect of a good recovery after an early secondary suture than after primary suture". Admittedly some of the injuries in their series were of the more extensive variety, though their records contain many cases of the type now under discussion. In explanation of the generally poorer results following primary suture they excluded sepsis as an adverse factor and attributed the chief faults to poor technique, inadequate resection of the damaged nerve ends and excessive post-operative tension. Are these faults to be regarded as directly due to the time at which the repair was effected or are they to be attributed to other agencies? Though poor technique is not a correlate of the time factor, it is conceivable that

inadequate resection and undue tension might have been consequential to conditions that were present at the time the immediate suture was performed. Thus the development of intraneural fibrosis subsequent to the original repair may have reversed what was apparently adequate preparation of the nerve ends at the time of operation. Again the excessive post-operative tension leading to suture line separation could presumably have been due to an inability at the time of primary repair to utilize mobilization and limb posture to the desired degree in order to permit the union of widely separated nerve ends without tension; the resultant tension may also have been aggravated by post-operative movement.

Seddon (1944) believes that "even when a nerve is divided so cleanly that it can be sutured without sacrifice of any of its substance, there is always a small gap to be closed" owing to the retraction of the nerve ends. In order to reduce this, he believes that either the part must be postured or the nerve mobilized. The former procedure has, in his opinion, a limited application in that posture may not relax the nerve unless the site of suture approximates to a joint while it may not be feasible for other reasons. Mobilization, demanding as it would the opening up of uninvolved tissues and tissue planes, is unwarranted at the time of primary suture.

Seddon advances two additional advantages in support of early secondary suture, which are based on the belief that a short delay permits tissue to return to a state which facilitates repair. (i) The nerve ends can then be held in apposition more effectively because the epineurial thickening consequent on the injury permits more secure sheath union than the more delicate tissue normally comprising the nerve sheath. (ii) After primary repair the suture line cannot be transferred to a new bed, but must be left in the wound surrounded by healing tissues. As a result the suture line ultimately becomes linked to surrounding tissues and structures, which may, when movements are commenced, pull on the nerve at a particularly vulnerable point. In early secondary suture this can be avoided by approaching the nerve clear of the primary scar, and the expectation is that "when movements are started it is certain that neither the scar of the original wound nor that of the secondary operation will be grossly adherent to the nerve". As Seddon so aptly puts it, "the delayed operation converts the suture from a procedure carried out under restrictions into one in which the surgeon is free to do as he wishes".

It would seem from these arguments that the disadvantages of immediate suture are essentially of a technical nature. Consequently, if union could be effected without tension in a field where the local damage was so slight as to minimize scarring, there should presumably be nothing to contraindicate immediate suture. In fact the present inquiry has shown that lacerations occur in which the nerve is so cleanly severed that there is practically no loss of substance. In these cases end-to-end suture can be performed easily and successfully either without mobilization or posture, or with a degree of limb flexion which is consistent with the conditions of the injury. The most rapid and successful recoveries recorded in this series followed immediate suture of the median nerve in one patient (Case 226) and of the lateral popliteal nerve in another (Case 335). It would therefore be unfortunate if the advocates of early secondary suture created the impression, as they appear to do, that primary suture should never be undertaken.

Primary suture, when the nerve is cleanly severed and not bruised, has one great advantage in that, despite the delicate nature of the normal sheath, it can be satisfactorily performed with little or no preparatory trimming of the nerve ends, so that there will be a minimal disturbance of the funicular arrangement at the suture line. This means that there will be a close, if not

complete, correspondence between the funicular patterns of the opposed nerve ends. It will be shown elsewhere that one of the most serious factors limiting recovery is the wasteful regeneration of axons into the interfunicular spaces of the distal stump. To avoid this it is essential to have the funicular patterns at the nerve ends corresponding as closely as possible. Funicular plexus formations, however, lead to such rapid and extensive changes of the funicular pattern that destruction or resection of more than a few millimetres of nerve can be expected to leave the opposing ends with dissimilar funicular patterns, the degree of dissimilarity depending on the length of the intervening gap (Sunderland, 1945; Sunderland and Ray, 1948). The danger of unnecessarily sacrificing nerve tissue when preparing the nerve ends for repair is therefore evident. If, immediately following the injury, the nerve ends are only anchored or left apart, they become involved in scar tissue as healing occurs, and no matter how slight this may be, some trimming is inevitable at the second operation. This involves a loss of nerve tissue which may be sufficient to produce a considerable and significant dissimilarity in the funicular pattern. The advocates of early secondary suture admit that "naturally, a small resection, sufficient to expose healthy bundles, will have to be performed"; they have, however, failed to appreciate just how significant this may be, even with restricted resections.

An additional argument advanced in favour of early secondary repair is that a short delay introduces two conditions which are more favourable for regeneration.

(i) Experimental work in the rabbit on Schwann cell activity at the nerve ends, upon which union and the success of regeneration is believed largely to depend, was found to be at its maximum between the nineteenth and twenty-fifth days after severance of the nerve (Abercrombie and Johnson, 1942). Since all the information required to permit an assessment of the relative influence of each of the several factors affecting the extent and quality of regeneration in the individual lesions was not available, it is not possible to gauge the influence of Schwann cell activity in the repair of human nerves. However, direct inspection of the suture site some time after union (for example, when the nerve was reexposed for transposition), together with an examination of the course of regeneration and the quality of the end result following repairs within and outside the period of maximum Schwann cell activity in the rabbit, provides sufficient evidence that this factor is either not operating in human material or, if it is, then it is of little signficance.

(ii) It has been stated that immediate suture exposes the regenerating axons to obstacles, in the form of the produces of Wallerian degeneration, to their advance down the distal stump. After axonotmesis, however, regenerating axons descend along that section of the nerve below the level of the injury earlier and more rapidly than after suture and function is ultimately completely restored. In their growth the axon tips must contend with the same products of degeneration as do those which regenerate after severance and repair, since the Wallerian degeneration resulting from the two types of injury differs, so far as can be detected, in no significant respects. Thus there is very good reason for believing that the presence of such debris does not impair the regenerative processes.

Conclusions.

There is nothing to contraindicate immediate repair when the following conditions are present:

(i) The nerve is cleanly severed and the local tissue damage is minimal and suggests that the residual scarring will be negligible. This represents a

set of conditions that the surgeon would find it difficult to repeat or improve when reentering the region at a later date.

(ii) The nerve ends can be found easily, so that no extension of the wound is required to locate them.

(iii) The nerve ends can be securely and easily sutured without mobilization and without tension.

(iv) Posture, if required to effect satisfactory union, does not introduce any complications which would adversely influence repair or aggravate scarring.

(v) There is no infection.

On the other hand, secondary repair, which should be performed immediately local conditions are favourable, is indicated when:

(*a*) The adjacent extraneural tissues are so extensively damaged that involvement of the severed nerve in the subsequent scarring is inevitable.

(*b*) It is impossible to assess the full extent of the damage to the nerve.

(*c*) There is a loss of nerve tissue with bruising and raggedness of the nerve ends which would necessitate extensive resection and mobilization in order to effect a secure union and perhaps even then only under tension with the limb adversely postured.

(*d*) The wound is infected.

"The delayed operation converts the suture from a procedure carried out under restrictions into one in which the surgeon is free to do as he wishes. The loss is perhaps three or four weeks and there is the discomfort of an additional operation. The gain is not one that can be assessed with accuracy, but it is considerable" (Seddon, 1944). All will agree with the wisdom of these remarks.

VII. When Should a Sutured Nerve be Reexplored and Resutured?

This question requires a separate consideration of: (1) How long should one wait for signs of returning function to appear after the first repair before performing resuture? (2) When should a sutured nerve that has shown some recovery be reexplored and resutured in an attempt to obtain a better result?

As a preface to a consideration of these matters it is important to know whether or not the interval elapsing after the first suture imposes any restrictions on the employment of resuture. There are not sufficient data in this series to allow an expression of opinion. Stopford (1922) concluded from an analysis of 271 cases that

> a delay *per se* of twelve to eighteen months had no appreciable effect upon the extent of recovery. If the interval exceed that time the prognosis was not so good when the suture had been performed in the distal part of the limb; whereas, in the proximal part, a delay of two or three years did not prejudice the chances of success . . . . Resuture does not appear to be a hopeful procedure if three years have elapsed since the time of injury.

How Long Should One Wait for Recovery to Follow the First Suture?

This will depend in large measure on the conditions obtaining at the first repair. So much tension may be required on that occasion to obtain end-to-end union that the prospects for recovery are recognized to be not good and resuture accordingly planned at the time (Case 322). However, accepting that local conditions were considered by the experienced surgeon to be favourable, how long should one wait for recovery to appear before resorting to resuture? Unless we have accurate information on this point, in many cases in which repair would be followed by satisfactory recovery, premature

and unnecessary resuture will be performed, with consequent loss of time, further deterioration in the peripheral mechanism and no promise of a better recovery.

The interval between the time of repair and the onset of recovery is due to the delay at the suture line before axons enter the distal segment, the time taken by them to descend and reach their end organs and for the restored pathway to become functionally efficient. This interval is obviously influenced by several factors, such as the distance that the regenerating axons must grow in order to reinnervate individual muscles, but in general an analysis of the course and end result of regeneration in the cases reported here shows that the onset of recovery may be considerably delayed and still proceed to a satisfactory end result. The findings of this inquiry indicate that there is good reason for delaying reexploration and resuture for seven months (which would cover all but the exceptional cases) unless conditions at the initial operation are such as to justify earlier interference; an exception is median

TABLE XX.

Information Relating to the Interval, in Months, Elapsing between Repair and the Onset of Recovery.

Nerve.	Onset of Voluntary Contractions.		Appearance of Sensibility to Pinprick.
	Proximal Muscles.	Distal Muscles.	
Radial nerve:			
Distal half of the upper arm (4 observations)	5 to 6 months (brachioradialis and radial extensors of the wrist)	8 to 10 (thenar muscles)	
Median nerve:			
At and above the elbow (2 observations)	7 to 8 months (*pronator teres* and *flexor carpi radialis*)		10 to 12 (hand)
Wrist (6 observations)		2 to 6 (intrinsic thenar muscles)	3 to 5 (hand)
Ulnar nerve:			
At and above the elbow (13 observations)	3 to 7 months (*flexor carpi ulnaris*)	10 to 20 (hypothenar muscles)	11 (hypothenar area)
Proximal part of the forearm (3 observations)		8 to 12 (hypothenar muscles)	4 to 7 (hypothenar area)
Wrist (3 observations)		4 to 10 (hypothenar muscles)	4 to 7 (hypothenar area)
Sciatic nerve and its popliteal divisions:			
Buttock (1 observation)	11 to 14 months		
Mid-thigh (1 observation)	5 to 8 months		
Popliteal fossa (1 observation)	7 to 9 months		

nerve repair at the wrist following which signs of returning function should be evident by five months (see Tables II, V, X, XIII, XVI and XVIII for details). Foerster (1929) reports an average interval of 5·5 months (variation 1 to 16 months) between repair and the first sign of motor recovery, while Stopford (1920) and Björkesten (1947) give values of 3·0 to 7·0 and 6·6 to 10·3 months for the arm and 5·0 to 25·0 and 6·5 to 14·6 months for the leg respectively, the particular value in any patient depending *inter alia* on the nerve and the level of the repair.

Recent literature (for example, Woodhall and Lyons, 1946; Zachary and Holmes, 1946) contains examples, in addition to Case 225 (radial nerve repair) in this series, which show that occasionally resuture is performed before sufficient time has been allowed for signs of recovery to appear. In defence of the resuture in these cases it is stated that histological examination of the excised suture site reveals conditions that are incompatible with

satisfactory regeneration. Disruption of the suture line and unfavourable conditions attributable to faulty technique at the initial operation certainly demand immediate correction. The use of a radio-opaque suture material will assist the earlier recognition of the former, while faulty technique can be remedied only by seeing that these cases are directed into the hands of those who are competent to deal with them. With the knowledge that disruption at the suture line has occurred, and with the suspicion that technique has been faulty, the question of awaiting signs of regeneration does not arise and immediate reexploration is justified. Excluding these two groups, however, there remain those occasional cases of too early reexploration in which scar tissue and neuroma formation at the suture site are held responsible for the failure of regeneration. Though this might well be the case, some doubt remains, since the explanation is purely inferential in that we are unaware of the conditions obtaining at the suture line when satisfactory regeneration does occur, while it is known that neuroma formation is not incompatible with satisfactory recovery. Regenerating axons will overcome what appear to be considerable obstacles to their growth and, when sufficient time has not been allowed for the appearance of recovery, it is conceivable that the conditions reported as incompatible with recovery might not in fact have been a serious bar to regeneration. Further examination of this question, however, must wait until detailed information is available concerning the course of regeneration and the end result following the resuture. It would, for instance, be interesting to know precisely when recovery did appear in these cases of resuture and whether the onset was delayed in comparison with the interval between the two repairs, which was at that stage considered to denote failure of regeneration. Unfortunately there is no way of ascertaining whether they fared any better after the resuture than they would have had there been no second interference.

Conclusions.—The only justification for reexploration and resuture before adequate time has been allowed for signs of recovery to appear are: (i) confirmed disruption at the suture line and (ii) when the first suture has been performed under such unfavourable conditions or with such poor technique that little recovery can be expected. Excluding these two groups, it would be wise, in order to avoid unnecessary resuture, to refrain from reexploring until ample time has been allowed for signs of recovery to appear. Though the occasions on which premature resuture has been performed are probably not numerous, the danger of the practice requires stressing lest it grow. Resuture should never be lightly undertaken, since there is no guarantee that the patient will fare any better after the second operation, the onset of recovery will be further delayed and the intraneural anatomy will be further disturbed by the additional resection required. Moreover, the resection adds to the retrograde neuronal reaction and introduces another gap, which can be closed only by further stretching of the nerve. For these reasons it is advisable to delay considerations of resuture for at least five months after repair of the median nerve at the wrist and for a maximum period of seven months after other repairs. Such delays will not significantly affect the end result if resuture is ultimately required.

When Should a Sutured Nerve that has Shown Some Recovery be Reexplored and Resutured in an Attempt to Obtain a Better Result?

It should be noted that no matter how well the suture is performed the recovery is always incomplete. Those who report complete restoration of function have not presented conclusive evidence in support of their claims. The residual impairment of function in the field of the injured nerve is

maximal (i) in the most distal muscles which combine to give those digital movements upon which manual dexterity depends, and (ii) for tactile and proprioceptor sensibility, upon which skilled digital movements and the stereognostic sense are so dependent. Consequently the failure of these functions to recover may be disregarded when assessing the end result prior to determining whether or not resuture is justifiable. For the purposes of the subsequent discussion the recovery will be classed simply as negligible or useful. Negligible recovery will be defined as that which is of no functional value to the patient. Useful recovery will be defined as that in which (*a*) the proximal muscles are contracting to give useful movements, (*b*) some individual voluntary movements of the digits are possible as the result of limited recovery in the intrinsic muscles of the hand, and (*c*) cutaneous sensation has been restored to a level at which trophic disturbances are fully or significantly corrected and the protective features are present.

When should one be satisfied with the end result and when can one feel justified in advising a second operation in an attempt to improve function? In order to establish guiding principles for deciding the policy to be adopted in regard to any individual patient, the cases may be arranged in three groups:

1. Cases in which the conditions at the original operation were considered, by one competent to judge, so unfavourable for end-to-end suture that little recovery was expected. Further attempts at repair in these cases are contraindicated.

2. Cases in which, at the original operation, local conditions were wholly favourable for repair, the technique of suture was faultless and any subsequent separation at the suture line could be excluded. If negligible recovery results, there is nothing to be lost by performing a second repair. If, on the other hand, some recovery has occurred, what is to be done? In these cases there is no way of ascertaining whether a second repair would be more successful than the first, since no reliable information is available regarding the quality of the recovery following the first and second repairs respectively in the same individual and under favourable conditions on each occasion. This seems to be the only conclusive way of determining whether or not a second repair can be expected to improve the result of a suture that has been well performed. On theoretical grounds, however, there is reason for believing that the resuture may introduce additional complications, such as an increased disturbance of the internal anatomy of the nerve, further retrograde neuronal reaction, and the closure of another gap in the nerve leading to further stretching. It would therefore seem that if a useful recovery has been recorded one should rest content.

3. Cases in which there is reason for believing that the technique at the original operation was faulty, with perhaps some disruption at the suture line, so that the prospects for effecting an improved union at a second repair are good. Negligible recovery in such a case should be treated by reexploration and resuture. Recovery, even under such circumstances, may, however, reach a degree that makes it difficult to decide whether one should remain content or plan for something better. In view of possible difficulties introduced by resuture and the absence of any definite information that an improvement can be expected, it is felt that it is preferable in these cases to do nothing further.

VIII. NEUROMA FORMATION.

The incidence of neuroma formation based on personal observations made at the time of the repair was as shown in Table XXI.

When both proximal and distal bulbs were present the former was invariably the larger. The bulbs developed at the site where the nerve stumps entered scar tissue, and though adherent to and continuous with this tissue, they were rarely buried in it. The appearance suggested that the factor responsible for the formation of the bulb was the resistance offered to the sprouting axons and Schwann outgrowths by the intervening scar tissue which deflected them into a circumscribed mass.

The number of occasions on which there were neither proximal nor distal bulbs is interesting. In these cases the stumps passed, without any abrupt transition in structure, into a mass of scar tissue in which all continuity of the nerve trunk was lost; presumably the sprouting axons from above and

TABLE XXI.

Nerve.	Neither Proximal nor Distal Bulbs Present.	Proximal and Distal Bulbs Present.	Proximal Bulb Only.	Distal Bulb Only.
Radial	1	3	2	0
Median	4	1	3	0
Ulnar	2	6	6	0
Sciatic	1	0	1	0
Medial popliteal	0	0	2	0
Lateral popliteal	1	1	1	0

the developing Schwann threads from below had penetrated and become lost in the intervening scar tissue. Attention has previously been directed to the observation that lesions in continuity that are clinically complete, but which show a bulb at the site of injury, may recover spontaneously (Sunderland, 1947). Thus a palpable bulb beneath a scar on an injured nerve in which there is complete interruption of conduction is not necessarily a sign that spontaneous recovery cannot occur, while the figures given above demonstrate that the absence of a neuroma under the same conditions is no proof that the nerve has not been severed.

TABLE XXII.

Nerve.	Number of Repairs.	Number of Possible Observations.	Bulb Palpable Post-operatively.
Radial	10	5	5
Median	14	10	7
Ulnar	26	22	18
Sciatic	4	0	0
Lateral popliteal	4	0	0
Medial popliteal	1	0	0

The suture line was accessible to palpation in 37 of the 59 repairs. The incidence of post-operative bulb formation in this group was as shown in Table XXII.

The findings demonstrate that there was a high incidence of post-operative neuroma formation. The incidence was in fact as high after suture as before among those patients (excluding cases of immediate repair) on whom personal observations of the nerve ends and suture line were made at and after repair. Furthermore, the size of the bulb that formed post-operatively appeared, in the majority of cases, to approximate to that present before operation.

IX. INTRANEURAL FIBROSIS.

The incidence, extent and severity of intraneural fibrosis have been evaluated on the length of nerve that it was necessary to resect in order to expose a condition favourable for repair and on the results of the histological examination of the resected tissue. On this basis the following conclusions appear to be justified.

1. The intraneural changes were proportional to the extent and severity of the injury to surrounding tissues and to the severity and duration of any infection. Intraneural fibrosis, however, appeared to result more from direct trauma to the nerve than from a spreading inflammatory reaction when the wound was infected.

2. The intraneural reaction did not appear to be as extensive or as severe as that reported in material from World War I. Possible explanations are, firstly, the high incidence in the recent conflict of perforating injuries from high-velocity missiles, which produced little tissue damage, and, secondly, a reduced incidence of severe infection as the result of advances in chemotherapy and perhaps the terrain of war (sparsely populated areas, such as jungle and desert).

3. Normal bundles were frequently seen traversing areas of advanced interfunicular fibrosis. The findings suggested that the perineurium is particularly resistant to infection and to any surrounding reaction. For example, in Case 137 (sciatic repair) "healthy" funiculi were exposed within 1·0 centimetre of the extremity of the proximal stump despite the severe and prolonged infection and the amount and density of the scar tissue surrounding the site of severance. On the other hand, intraneural fibrosis was more extensive in the distal stump. Intrafunicular changes, when they occurred, appeared to follow vascular damage inside and/or outside the funiculus and when infection entered the funiculus through breaches in the perineurium.

4. A study of the literature suggests that the intraneural changes are due, essentially, to an ascending infective neuritis and that for this reason the changes in the proximal segment will be more extensive than those in the distal. In the present series, however, an examination of the resected material from some cases in which there was no sepsis showed an intraneural fibrosis that extended further distally than proximally. This would indicate that local mechanical injury was the factor responsible and that the resultant fibrosis may extend further distally than proximally.

5. Reasonable recovery occurred in some cases in which resection was considered inadequate because of persisting intraneural fibrosis; further resection, however, was impracticable in that it would have prevented end-to-end union. Assessments indicate that this recovery, though limited, is probably superior to that customarily obtained by grafting. This suggests the advisability of performing end-to-end suture under conditions that do not appear wholly favourable, so that every opportunity would be given for function to be restored to a stage that would make grafting unnecessary. Whether such a policy is justified must ultimately depend on the results of a comparison, in a large series of cases, of the recovery assessments following grafting on the one hand and end-to-end suture under unfavourable conditions on the other.

X. ON THE TRIMMING OF NERVE ENDS IN PREPARATION FOR END-TO-END SUTURE.

When nerve ends are being prepared for suture the practice is to trim them carefully until "healthy bundles" or "satisfactory cross-sections" are

exposed. The terms "healthy" and "satisfactory", however, remain undefined, while the term "healthy" is somewhat confusing in that it is unlikely that the faces of the opposing nerve ends will present the same appearance because of the degenerative changes that have occurred in the nerve below the lesion. From a survey of the literature on this subject these two terms are presumably used to denote a condition in which there is an absence of fibrous thickening, where the funiculi are clearly visible and fill the nerve, where the amount of intraneural connective tissue is minimal, loose in texture and soft in consistency, and where the funiculi of the proximal face have the characteristic appearance of cut normal funiculi and the exposed surface bleeds freely. It is possible to assess these features correctly and reliably only with the aid of some magnification, such as that provided by the use of dissecting spectacles.

Great caution must be exercised when examining the trimmed surfaces of the nerve ends to ascertain when morpohological conditions are optimal for union, because the amount (in contradistinction to the density) of the intraneural connective tissue together with the number, arrangement and degree of separation of the funiculi are all subject to a wide range of normal variation (Sunderland and Bradley). Failure to appreciate and recognize this range of normal variation introduces the danger of unnecessarily resecting normal tissue in an attempt to reveal an arrangement which the nerve does not normally show in that region. For this reason the concept that the picture of the nerve ends described above is the only normal arrangement, and therefore the one to be carefully sought when preparing nerve ends for union, is, in some respects, misleading.

Investigation has shown that the number of bundles in a nerve varies greatly from level to level, as also does the relationship of the funicular cross-sectional area to that of the entire nerve, the latter being a measure of the degree of separation of the funiculi. Thus the total cross-sectional area of the combined funiculi may normally be as low as 12% of that of the entire nerve trunk, indicating that the funiculi are widely separated by interfunicular connective tissue. Values for the percentage cross-sectional area of the nerve occupied by its component funiculi at various levels for individual peripheral nerves are available (Sunderland and Bradley) and they demonstrate that the number of funiculi and the amount (as opposed to the quality and density) of the supporting connective tissue are of little significance when deciding whether or not the nerve ends can be regarded as healthy or otherwise. This point is mentioned because it is felt that the cross-sectional picture of a large amount of supporting connective tissue with a few widely separated bundles may be regarded as pathological and the trimming consequently unnecessarily extended in the expectation of exposing a larger number of bundles with less interfunicular tissue. When assessing the suitability of the nerve end for repair the features to be relied on are not the number and compactness of the bundles, but the quality of the connective tissue and the appearance presented by the exposed face of each funiculus in the proximal stump.

Unnecessary trimming of nerve ends can be prejudicial to recovery, firstly, by increasing the distance between the nerve ends, which should be kept to a minimum so that the measures required to close the gap and permit end-to-end union will not result in harmful tension at the suture site, and, secondly, by increasing the length of nerve destroyed. The thesis will be developed elsewhere that the most mischievous factors militating against recovery are those that foster the wasteful regeneration of axons into the interfunicular spaces and these are introduced when there is a dissimilarity of

the funicular patterns of the opposing nerve faces. This dissimilarity is increased as the segment of nerve destroyed or removed in the surgical resection increases, and for this reason every attempt should be made to conserve nerve tissue when preparing the nerve ends for repair. Though the influence on regeneration of the size of the nerve defect is difficult to assess, because of the presence of secondary factors which cannot be excluded, it is known that the results after the closure of small defects are distinctly superior to those which follow the closure of large gaps (Merle d'Aubigné, 1946; Björkesten, 1947); such was the case in the present inquiry.

Of interest is the number of instances in which some regeneration, admitedly far from complete, has occurred when incomplete preparation of the nerve ends was unavoidable. In these cases inspection of the nerve ends prior to union and the subsequent histological examination of material removed at the time of repair indicated that little recovery could be expected in view of the inability to obtain conditions at the nerve ends which are normally regarded as essential for some recovery. This observation confirms that regenerating axons will overcome great obstacles in order to reach the distal stump, and in doing so are almost certainly aided by factors of which we are at present ignorant. Thus even when local conditions may appear unfavourable for recovery the subsequent course of events may bring some pleasant surprises.

XI. The Relative Merits of Various Suture Materials.

In view of the many variables influencing the extent and quality of recovery and the complicated way in which they operate, it was not possible to assess the influence on the regenerative process of the suture materials employed in the cases investigated. The observations indicate, however, that good recovery occurs when plain black silk, and even catgut, is used. Recent experimental and clinical work suggests that human hair, plain white silk and tantalum excite a minimal tissue reaction and provide the best means of effecting a union which will, at the same time, not impair the entry of regenerating axons into the distal stump (Guttmann, 1943; Tarlov, 1943, 1944; Spurling, 1945; White and Hamlin, 1945). It is possible, therefore, that the use of human hair and tantalum in the cases in which satisfactory recovery occurred would have resulted in a similar, or perhaps even better, degree of recovery. A tantalum wrap was used in only one case and it was not possible to assess its effect. Cliffton (1948) has reported that tantalum cuffs have not proved of value in the series of cases of peripheral nerve injuries investigated by him.

XII. Consequences of Post-Operative Stretching of Sutured Nerves.

Though end-to-end suture was effected without tension in the majority of those cases for which I have my own notes of the operation, this could, with few exceptions, be achieved only by a combination of mobilization and rerouting of the nerve and posture of the limb. Flexion of the joints was used extensively, while rerouting was confined to repair of the radial and ulnar nerves. When mobilizing the nerve, which was performed on a restricted basis, no attempt was made to strip branches from the nerve trunk in order to gain further lengthening. Previous investigations (Sunderland, 1945, and Sunderland and Ray, 1948) have provided data relating to the intraneural length over which the funiculi representing individual branches maintain their individuality; this is a measure of the distance for which a branch may be safely stripped without damage of the remaining funiculi and fibres in the nerve trunk. The distance for which a particular branch

may safely be stripped, however, is variable while the funicular anastomoses involving fibres of different branches may be so minute that considerable magnification is required to reveal them. This makes it impossible to decide at operation how far stripping of a branch can be continued without damage of fibres. The fibres of some branches, however, usually pursue longer isolated courses in the nerve than others, and this information is of help when mobilizing the nerve. Unfortunately values for these distances were not available when most of the sutures reported in this paper were performed, though preliminary investigations had indicated that the usefulness and practicability of the procedure were limited by microscopic but significant funicular anastomoses. As a result, it was decided to rely on measures to close the gap which did not require the stripping of branches.

In the cases investigated there was no way of accurately measuring the post-operative tension developed in the repaired nerve nor was it possible to establish a correlation between this factor and the residual disability owing to the absence of a full knowledge of all of the several variables influencing the extent and quality of recovery. As a result the consequences of post-operative stretching of nerves on the progress of regeneration could not be accurately assessed, though certain broad generalizations are permissible.

It is not easy to decide whether post-operative stretching is ever without harmful effect, because function is never completely restored after suture and in the present state of knowledge there is no way of deciding how much of the residual defect, no matter how small this may be, is directly attributable to the stretch. All that can be said from the present inquiry is that, in several cases in which good recoveries were recorded, the extent of the resections and the various manipulative procedures required to close the gap between the nerve ends were such that some stretching of the nerve must have occurred when extension of the limb was commenced three to five (for the arm) or four to six (for the leg) weeks after repair; in some of these the stretch must have been considerable. Thus it would seem that some degree of post-operative stretching is not necessarily incompatible with a good recovery. This accords with the experience of other writers.

There is a limit to the size of the gap that can be closed effectively by a combination of mobilization, rerouting and limb posture. Furthermore, this limit may be reduced by factors, such as extraneural injury or the fixation of the nerve by the attachment of its branches, which restrict the extent to which the various manipulative procedures can be utilized. If this limit is exceeded the nerve ends either cannot be approximated or, if they are, post-operative stretching results in separation at the suture line or the disruption of nerve fibres at levels elsewhere along the nerve.

Disruption at the Suture Line.—Premature post-operative stretching of the nerve is a common cause of disruption at the suture line. It is therefore important to know whether or not healing at the suture line proceeds to a stage where the tensile strength of the nerve at this level is fully restored, and the time for which the joint should be immobilized in order to permit the strongest possible union. Early post-operative extension probably has the advantage that the suture site is less likely to have become securely fixed to surrounding tissues, so that the tension which is developed is more evenly dispersed along the full length of the nerve, whereas following fixation it falls unevenly on either the proximal or distal segments, depending on the site of the repair with reference to the joint. However, if extension of the limb is commenced, or is accidentally or carelessly permitted before union is consolidated, separation of the nerve ends will occur at the suture line. The

regenerating axons will then be faced with additional obstacles to their entry into the distal stump, while those that have already entered it are in an immature state, and for this reason are probably more vulnerable to stretch. Disruption of the suture line occurring in this way is a common cause of failure of regeneration in sutured nerves. On the other hand, if immobilization is prolonged unnecessarily, the formation of periarticular adhesions is encouraged and these adversely affect the restoration of function.

Tensile strength determinations of sutured nerves in dogs and rabbits (Miller, 1921; Tarlov, 1947) indicate that the suture line achieves the tensile strength of the intact nerve within a period of three weeks. Tarlov wrote that "there is no reason to suppose that there might be any appreciable difference in the healing time of sutured nerves in man", but Miller, aware of the "individual differences in rapidity of repair in human beings", advocated a delay of four weeks for the ulnar and median nerves and six to eight weeks for the sciatic nerve before initiating extension of the limb. This experimental work suggests that, depending on the nerve, the suture line is as strong as it is ever likely to be four to eight weeks after repair. The clinical observation that rupture on extension occasionally occurs at levels other than the suture line confirms that the tensile strength at the site of union may be fully restored; in some of these cases, however, a contributing factor may be the firm adherence of the suture site to surrounding structures, so that the stretch falls solely or unevenly on either the proximal or distal segment, depending on the position of the joint with reference to the suture line.

Immobilization for longer periods than those specified is therefore unnecessary and definitely harmful in that it encourages those periarticular changes that impair the restoration of function following good regeneration.

There is ample evidence, however, that separation at the suture line sometimes occurs after the recommended period of immobilization. This is presumably due to some delay or variation in healing, which temporarily, or perhaps permanently, reduces the tensile strength of the nerve at this site. Impaired healing at the suture line could be due to one or a combination of the following:

(i) Technical errors in the performance of the suture. According to Miller (1921), "the epineural sutures of fine catgut or silk play little if any part in the strength of the suture line after the second week". This suggests that if there is a technical factor operating, it must be one that retards or adversely influences healing. This is in accord with Whitcomb's (1946) observation that "at no instance could the rupture of the anastomosis be found attributable to the suture material".

(ii) Post-operative infection, if present.

(iii) The likelihood that nerves sutured under great tension, even with the full assistance of posture, mobilization and rerouting, may draw apart before limb extension is commenced, a further separation subsequently occurring with extension. In order to assess the possible influence of this factor, the operation notes should state whether or not, at the conclusion of the various manipulative procedures to reduce the gap between the nerve ends, the latter could be joined only under tension.

(iv) Individual peculiarities of healing resulting in delayed or permanently impaired union.

(v) Delayed repair. It has been shown (Abercrombie and Johnson, 1942) that Schwann cell proliferation from the distal stump, upon which union is believed greatly to depend, is most active 19 to 25 days after division of the nerve. On this basis it might be argued that repair delayed beyond these time limits might present a greater obstacle to effective union. However,

when, in the material investigated, the gap separating the nerve ends before union, the measures required to close it, and the tension which must have been introduced by post-operative stretching are correlated with the extent and quality of the recovery, it will be seen that union occurs as rapidly and as securely after late as after early repair. Unless the data are interpreted in this way it must be assumed that the residual disability after delayed repair is always, and that following early repair is never, due to disruption at the suture line; such an assumption is unjustified. From this it may be concluded that the duration of the interval elapsing between injury and repair (within the time limits available in this study) does not significantly influence the rate and quality of healing at the suture line.

(vi) The possible existence of conditions in which, owing to incomplete preparation of the nerve ends, the union will be of a weaker type.

Disruption of Nerve Fibres at Levels other than the Suture Line.—If the suture line survives the post-operative stretching, the tension developed is distributed along the entire nerve, or, if the site of union has become firmly adherent to adjacent structures, it will be concentrated either proximal or distal to the site of fixation, depending on the position of the latter with reference to the joint. The consequences are likely to be more serious when the tension falls on the distal segment because it is then transmitted to the branches leaving the nerve below the point of fixation; tension falling above that level tends to slacken the branches leaving the proximal segment. The investigations of Takimoto (1916), Highet and Holmes (1943), Highet and Sanders (1943) and Denny Brown and Doherty (1945) have shown that there is a limit to which nerve fibres may be stretched and yet remain capable of functioning effectively and of regenerating after severance. However, we are unaware of the critical point at which stretch becomes incompatible with satisfactory regeneration, so that it is difficult to assess the maximum resection which is compatible with good functional recovery. In this connexion it should be noted that conduction in a nerve may be impaired by distortion which is insufficient to disrupt the nerve either at the suture line or elsewhere. Furthermore, conduction impaired in this way may subsequently improve when the nerve has had time to accommodate itself to the changed conditions. Thus I have recently had the privilege of examining a specimen from Mr. Hugh Trumble's collection, in which a pituitary neoplasm, escaping from the *sella turcica,* had stretched the right oculomotor nerve between the brain stem and the cavernous sinus to twice its normal length. Investigations on the acute stretching of nerves have shown that rupture occurs after approximately 10% to 15% of extension (Sunderland and Bradley). The absence of any clinically demonstrable disturbance of function in the somatic field of the oculomotor nerve which had doubled its length in one part of its course can best be explained on the assumption that the nerve was stretched so slowly that the somatic fibres had adequate time to accommodate themselves to the altered conditions.

Detailed records, from a large series of cases, of the extent of the resection, the site of the suture and the quality of the functional recovery will be required before it will be possible to decide confidently whether closure of a defect should be attempted by end-to-end suture or by the insertion of a graft. In this connexion the important factor is not the gap that can be reduced without subsequent separation at the suture line, but the gap that can be reduced to permit union which will result in good functional recovery. Highet and Holmes (1943) have already made a significant and valuable contribution in this regard. The values attributed to these authors

in Table XXIII were selected from data in their papers in the following way. A recovery of M3, S2, on their grading, was accepted as satisfactory. The greatest defect which could be closed by end-to-end union that was followed by recovery of a degree not less than this rating was selected for inclusion in the table. Grantham, Pollard and Brabson (1948) have reported on the closure of gaps at several levels in a much larger series of cases (Table XXIII). The closure of these gaps is said to have been consistent with successful recovery, though their definition of "successful" was unspecified. Forrester Brown (1921) has described gaps in peripheral nerves which allow of end-to-end suture, but her accounts of the subsequent recovery are too vague and unconvincing to permit a correlation between the length of the defect and the quality of the end result. Babcock (1927) has also listed gaps

TABLE XXIII.

Data Relating to the Maximal Nerve Defects which have been Closed by End-to-end Union which has Resulted in Good or Satisfactory Recovery.

Measurements are given in centimetres.

Nerve.	Level of Repair.	This Inquiry.	Highet and Holmes.	Grantham, Pollard and Brabson.
Radial	Axilla.	—	—	2·3
	Upper arm.	—	—	6·2
	Elbow region.	3·0 (Case 40).	5·5	3·4
Median	Upper arm.	—	—	6·0
	Elbow.	5·0 (Case 333).	—	6·0 to 10·0
	Upper forearm.	—	—	4·5 to 5·5
	Mid-forearm.	3·5 (Case 275).	—	4·5 to 7·0
	Distal forearm.	—	—	4·0
	Wrist.	2·0 (Case 108).	5·0	1·8
Ulnar	Upper arm.	7·0 (Case 183).	—	—
		6·0 (Case 207).	—	2·0 to 6·0
	Elbow region.	4·0 (Case 269).	—	5·2
	Upper forearm.	—	4·0	4·6
	Mid-forearm.	—	—	3·2 to 4·7
	Distal forearm.	3·5 (Case 38).	—	3·4 to 6·5
	Wrist.	—	4·0	—
Sciatic	Buttock.	6·0 (Case 122).	—	6·0 to 8·5
	Thigh.	—	—	6·0
Medial popliteal ..	Lower thigh.	—	—	5·2
	Popliteal fossa to soleal arch.	4·0 (Case 155).	—	4·5
Lateral popliteal ..	Lower thigh.	5·0 (Case 9).	5·0	6·4

that can be closed in various nerves, but he did not consider either the effect of post-operative stretching on the suture line or the subsequent course of recovery.

The present series is unfortunately too small to provide evidence of a conclusive nature, while most of the resections have not been sufficiently extensive to be incompatible with recovery. Nevertheless there is sufficient detail to make the records of value when they are combined for final analysis with those of other investigators. The greatest gaps in this series (measured with the parts fully extended), requiring manipulative procedures to close them, which resulted in post-operative stretching but in which good or satisfactory functional recovery was obtained, are given in Table XXIII.

XIII. THE INFLUENCE OF THE EXTRANEURAL DEFECT ON THE ASSESSMENT OF THE END RESULT.

Any associated extraneural injury, such as the extensive destruction of muscle tissue and tendon and the direct involvement of joints, may impose a restriction on the restoration of function in the field of the involved nerve following satisfactory regeneration. Unfavourable end results after delayed

repair may also be due to, or aggravated by, neglect of the peripheral tissues prior and subsequent to repair which encourages those irreversible changes in the peripheral motor mechanism that are prejudicial to recovery.

It should not, therefore, be surprising if, in the face of a crippling residual defect, which is attributable solely to extraneural injury or to the development of irreversible changes in muscles and joints as the result of the gross neglect of the peripheral mechanism, repair ends in failure regardless of the number of axons that regenerate, reach their destination and maturate into functionally efficient pathways. In this connexion it should be remembered that late sutures are in most cases necessarily delayed because of the presence of associated complications (for example, infection and soft tissue, bone and joint injury), so that it is in these cases that the restoration of function is most likely to be impaired by extraneural changes. It is therefore important, when assessing the end results of suture as a basis for estimating the influence of delayed repair on the regenerative process, to differentiate carefully between the residual disability which is due to extraneural factors and that which is consequent on a deficiency in the regenerative process. Admittedly this may sometimes be difficult, but should always be attempted. This has been the policy throughout this investigation.

XIV. THE COURSE OF RECOVERY.

Recovery occurs rapidly in the first year, while further improvement takes place more slowly in the second and gradually slows until a stationary condition is reached by the fourth year. Recovery, however, may reach a stationary and satisfactory state within eighteen months from the onset, but it is usual for the process to be spread over a longer period. In the early stages (first year) recovery is due principally to the regeneration of axons and the reestablishment of functional pathways. Subsequently, and particularly in the terminal stages, the improvement is due to a combination of (i) the delayed maturation of pathways previously established rather than to the downgrowth of any new fibres, (ii) the "use" hypertrophy of reinnervated muscle fibres, and (iii) the organization of new patterns of activity at central levels. This generalization accounts for the pattern of recovery in most cases. If the end result assessments are to be convincing the follow-up must exceed three years. The findings demonstrate that a five-year follow-up is adequate for a reliable assessment of the extent and quality of the end result.

The early onset of recovery is no guarantee that regeneration will proceed satisfactorily and culminate in a successful end result, while successful results occasionally followed the delayed reappearance of function. The time at which recovery first appears does not, therefore, provide a reliable guide to prognosis.

The observation that good recoveries may follow a delayed return of function emphasizes the importance of allowing sufficient time for the reappearance of returning function before contemplating resuture.

Björkesten's (1947) statement that: "Except in low injuries the reinnervation of the small muscles of the hand, especially in the ulnar nerve cases, seldom becomes evident before two years after operation" was not confirmed.

The times at which signs of returning function can be expected are given in Table XXII.

Providing the local conditions are favourable for repair, good results can follow repair which has been delayed for periods up to at least 11 months.

Among the patients who fared badly there were instances, both after early and delayed repair (more than two years after injury in two cases), when function reappeared at about the same time as it did in those cases in which the patients progressed to a good recovery. Why did regeneration fail to progress satisfactorily after signs of returning function became evident within the period recorded for cases in which a good recovery ensued? Presumably it is due to a deficiency in the regenerative process, which limits the number of axons reaching appropriate end organs and the number of peripheral units that are restored to full activity on reinnervation. This is best accounted for on the basis of:

(i) Retrograde neuronal degeneration.

(ii) The loss of regenerating axons at the suture line and into interfunicular spaces and down functionally unrelated endoneurial tubes. This loss is increased by: (*a*) dissimilarity in the cross-sectional area of the nerve ends consequent on denervation shrinkage of the distal stump; (*b*) dissimilarity in the funicular patterns of the nerve ends, which increases with the length of nerve destroyed and resected; (*c*) denervation shrinkage of the endoneurial tubes and the morphological changes occurring in them, which restrict the enry and subsequent descent and maturation of the regenerating axons; (*d*) scarring at the suture line.

(iii) The development of irreversible changes in the end organs, which limits their capacity to function efficiently on reinnervation.

Though factors (ii) (*a*), (ii) (*c*) and (iii) may be held responsible for the failure of regeneration to progress satisfactorily after delayed repair, they are entirely blameless after immediate or early repair. Furthermore, the evidence presented in this paper suggests that the irreversible changes which develop in the distal stump and end organ as the period of denervation increases do not operate in a significant manner where repair has been delayed for periods not exceeding 11 months. From this it may be inferred that the significant factors restricting recovery are (i), (ii) (*b*) and (ii) (*d*).

After the repair of the median and ulnar nerves signs of cutaneous sensory recovery usually appeared in the hand before the onset of voluntary contractions in the intrinsic muscles of the hand. The reasons for this have been discussed in a previous section ("Median Nerve Suture: Comments").

In the majority of cases there was either no improvement of joint sensibility or this function remained very defective even when cutaneous sensation showed a good recovery.

XV. INFLUENCE ON THE COURSE OF RECOVERY OF THE CAUSATIVE INJURY.

In general, cases of nerve repair following laceration severance fared better than those in which a missile was responsible for the injury. This is attributed to:

(i) The destruction of a much greater length of nerve in the gunshot group owing to the greater severity of the causative injury and the more extensive intraneural changes introduced by infection and scarring when these were present. This resulted in a greater dissimilarity in the funicular patterns of the nerve ends at the suture line and also necessitated union under tension, both of which rduce the chances of a successful repair.

(ii) The retrograde neuronal changes induced by the injury, which influence the extent and quality of the regeneration. These are more serious in the gunshot group because of the greater severity of the injury.

(iii) The predominance of gunshot injuries at proximal levels and of the laceration injuries at more distal levels. Recovery in the hand is usually less effective after repair above the elbow. The reasons for this and the influence of the level of the repair on the course of recovery are fully discussed in Section XVII.

XVI. INFLUENCE ON THE COURSE OF RECOVERY OF THE INTERVAL BETWEEN INJURY AND REPAIR.

There is general agreement that a severed nerve should be sutured immediately local conditions are considered favourable for efficient repair. In this connexion the relative merits of immediate and early secondary repair have already been discussed. Though the overwhelming superiority of these two forms of repair has been convincingly and securely established, and though there is absolutely no justification for the delay of suture beyond the time when it can be performed, it is, nevertheless, important to know the effect of the interval between injury and repair on the extent and quality of the recovery for the following two reasons:

(i) Awaiting signs of spontaneous recovery in lesions in continuity involves delays of up to six to nine months (Sunderland, 1947). Do such delays adversely affect the end result if resection and suture are ultimately required?

(ii) Considerable delays in the repair of severed nerves are often inevitable owing to, *inter alia*, gross injury to neighbouring parts and prolonged and severe infection. After what delays are attempts at repair no longer worth while?

Most writers have expressed the belief that the result deteriorates with an increasing interval between injury and repair, though this opinion is based on the observation that, in any given series of cases, the number of successful results after early repair will far exceed that after late secondary repair. This is unquestionably the case, but attention has already been directed to the fallacy of fixing the point at which the delay is responsible for a significant deterioration of the end result solely on the basis of a higher incidence of good recoveries after early suture when other factors that are known to influence the end result have not been and cannot be excluded. It should not be forgotten that late secondary repair is often imposed by conditions which considerably increase the hazards of repair, for example, more severe injuries with much destruction of tissue, prolonged and severe infection, and the presence of large defects in the nerve. Unfavourable end results under such adverse conditions should not be surprising. The significant observation which appears repeatedly in the literature is that exceptional recoveries do follow repair that is delayed for considerable periods. The most recent comment is by Björkesten (1947), who writes as follows:

> The frequency of positive results in secondary sutures is to a surprisingly small extent dependent on the interval between trauma and operation.
>
> Only after operations performed during the third year are the negative results predominant. The qualitative results deteriorate continuously, but the rapidity of this process increases during the last quarter of the first year, when the qualitatively unsatisfactory results already outnumber the satisfactory ones. Yet good recoveries may still be obtained even in cases operated during the latter half of the second year of trauma.

There is ample evidence in this paper to the effect that very good recoveries can occur after repair which has been delayed for periods ranging from six to eleven months; furthermore, in this group the course of regeneration, from onset to termination, did not differ significantly from that recorded after early repair. Holmes and Young (1942) have shown experimentally that "the

power of a central stump to send out new fibres is not reduced if it be severed a second time and then sutured, either within a week or after an interval as long as a year".

Despite the accepted belief that the result deteriorates with an increasing interval between injury and repair, little information is available as regards the point at which this deterioration becomes significant. It may be inferred from the clinical findings of Björkesten (1947) that they assume significance "during the last quarter of the first year", while the experimental investigations of Holmes and Young (1942) indicate that delays, "especially those greater than five or six months, produce conditions which at least are liable to retard recovery and may permanently prevent its completion". On the other hand, Stopford (1920) states that, excluding cases with widespread intraneural changes, "a delay of twelve to eighteen months appears to have no marked effect upon the date or extent of the recovery".

The results of the present inquiry show that repairs undertaken after delays of up to 11 months may be followed by very good recoveries, which are equally as good or better than those following immediate or early secondary suture.

Though the data in the clinical literature do not permit the establishment of a time limit beyond which repair would be useless, the work of Bowden and Gutmann (1944) on the biopsy examination of denervated human muscle indicates that irreversible changes, which are incompatible with recovery, are evident at three years.

XVII. INFLUENCE ON THE COURSE OF RECOVERY OF THE LEVEL OF REPAIR.

Etzold (1881), Lehmann (1921) and Foerster (1929) noted that high repair is associated with a generally poorer result that low repair, while Stopford (1920), on slender evidence, concluded that "the prognosis was more favourable the nearer the suture is to the spinal cord".

An analysis of the end results in the cases investigated indicates that after high repairs the distal muscles recover less frequently and, when they do, to a lesser degree than the proximal. The reasons for this will be detailed elsewhere (Sunderland and Bedbrook). Briefly, following repair in the proximal part of the limb, conditions are more favourable for recovery in the proximal than in the distal muscles because: (i) The nerve fibres supplying the proximal muscles occupy a greater cross-sectional area of the nerve at the site of suture. (ii) They are better localized at proximal levels than the fibres destined for structures further distally. (iii) The common action often shared by the proximal muscles assists in the restoration of function. Thus proximal muscles often combine as prime movers in executing movements and for this reason the reinnervation of one member of the group by fibres originally supplying another does not greatly disturb the pattern. Consequently, for the purposes of assessing the restoration of the fibre pattern during recovery, these muscles may be regarded as forming a functional unit. The two heads of gastrocnemius and soleus, the hamstring group, the peronei and the extensors of the wrist are examples in point. On the other hand, the muscles controlling the digits function as independent but well-integrated and coordinated systems in every movement, combining to give that delicacy, refinement and precision of action which, in the case of the hand, is the basis of manual dexterity. In these complex and finely adjusted movement patterns each muscle has a specific role to play. Consequently any disturbance of the fibre pattern during the regeneration of fibres to these muscles seriously

limits the restoration of function. (iv) The distal muscles remain denervated for longer periods owing to the greater distance to be covered by the regenerating axons and their slower rate of growth at distal levels; the time is thereby extended for the development of those changes which restrict the restoration of function even when the axonal pathway to the end organ has been reestablished.

The quality of the sensory recovery in the hand following high repairs is not as good as that following repairs at the wrist, for the reason that at proximal levels the sensory fibres are scattered and thoroughly mixed with motor fibres, while at the wrist the fibres for individual cutaneous nerves are so well localized that the entry of regenerating cutaneous fibres into corresponding or closely related endoneurial tubes is greatly favoured.

At levels in the forearm and leg where no localization of branch fibres obtains, recovery will, other things being equal, favour structures innervated by branches whose fibres occupy the greater cross-sectional area of the nerve. At the wrist, where the fibres of the terminal branches are partly or sharply localized in the nerve trunk, such a localization will compensate in part, providing correct funicular relations can be maintained during repair, for any disadvantage pertaining to a branch because of the small number of its component fibres. Regardless, however, of the degree of localization obtaining, the more regenerating fibres which correspond to a particular structure, the greater are the chances of recovery in that structure, though the quality of the recovery will depend on the number of the fibres reaching their destination and the extent to which they reconstitute the pattern. For this reason repairs at the wrist are followed by better recoveries in the hand than repairs at proximal levels.

Thus at the wrist 94% of the funicular cross-sectional area of the median nerve is occupied by sensory fibres and 6% by the fibres for the thenar muscles, while the fibres for the various terminal branches are well localized in separate funiculi or groups of funiculi. Above the elbow, however, the terminal sensory fibres occupy 66% of the funicular cross-sectional area of the nerve and the terminal motor 4%; here, however, the fibres from the different terminal branches are now intermingled and are widely dispersed over the component funiculi. Similar conditions obtain in the case of the ulnar nerve, where the values for the sensory and motor components at the wrist are approximately 56% and 44% respectively, while the corresponding values above the elbow are 35% and 28%.

The intensity of the retrograde neuronal reaction, which is a factor influencing regeneration, varies inversely as the distance of the site of injury from the cell. For this reason the consequences of high lesions should be more serious than those following low injuries. In general there was a much poorer recovery in the hand after repair in the proximal than in the distal part of the limb. Retrograde neuronal reaction cannot, however, be held wholly or even predominantly responsible for this difference in the end result in cases of high and low repair, since after the former there was a good recovery in the proximal muscles, while other factors, such as fibre mixing, fibre localization and the number of fibres destined for individual structures operate to affect the extent and quality of the recovery in the hand. Furthermore, the majority of high lesions were caused by missiles, and these injuries are known to introduce additional factors that adversely affect the end result. In this connexion it is of interest that in several cases the repair of a laceration injury of the ulnar nerve in the vicinity of the elbow was followed by a satisfactory recovery.

XVIII. INFLUENCE ON THE COURSE OF RECOVERY OF PREVIOUS INFECTION AND SCARRING IN THE TISSUES SURROUNDING THE SUTURE LINE.

The severity of previous infection and the extent and quality of the residual scarring in the healed wound affect the repair of nerves in two ways:

(i) By involving the nerve stumps. This means that more extensive resections are required in order to provide "satisfactory" surfaces for union, thereby increasing the gap to be closed, and the dissimilarity in the funicular pattern on each side of the suture line, which combine to diminish the chances of a successful repair.

(ii) By influencing the quality of the bed which carries the suture line. Though new beds could often be provided for the median and ulnar nerves, this was rarely possible in the case of the radial and sciatic nerves. It was difficult to isolate and evaluate this factor.

The quality of the recovery was indirectly related to the severity of the injury to, and the degree of infection in, the surrounding tissues. This occurred regardless of whether or not the suture line was transferred to a new and more favourable bed, which suggested that a poor recovery was due predominantly to factors other than those associated with the nature of the bed. Though the possibility remains that in certain cases an unsatisfactory bed may have contributed to the poor result, it would seem that infection and scarring in the vicinity of the severed nerve exercise their harmful effects principally by increasing the amount of nerve which requires to be excised in the preparation of the nerve ends for repair. According to Stopford (1920) "the prognosis is bad when a satisfactory bed cannot be procured and the nerve has to be left in relation with scar tissue", though he failed to exclude the influence of other factors in arriving at this conclusion.

XIX. INFLUENCE ON THE COURSE OF RECOVERY OF A CONCOMITANT VASCULAR INJURY.

The main artery to the limb was ligated in five patients, presenting six nerve lesions, in whom end-to-end suture of the severed nerve was possible. In a further three injuries at the wrist the ulnar artery, in addition to the ulnar nerve, was severed; however, the anastomosis between this vessel and the radial artery is so free that it is doubtful whether the field of the involved nerve was subjected to any circulatory embarrassment in these cases.

A true evaluation of the influence of the associated vascular injury on the processes of regeneration was not possible owing to the small number of cases available for investigation and our imperfect knowledge of the variables affecting the extent and quality of the recovery. There was a good result in two cases (brachial, Case 207, and ulnar, Case 139, artery ligation), a satisfactory result in one (brachial artery ligation; Case 333), a fair result in one (brachial artery ligation, Case 322, median repair), and poor recovery in five (three examples of ligation of the brachial artery, Cases 182, 277 and 322, ulnar repair, and two of the ulnar, Cases 307 and 325). In the poor recovery group several unfavourable factors were operating simultaneously to reduce the effectiveness of regeneration and there was no way of estimating the extent to which the vascular injury contributed.

In the full series of nerve injuries from which the suture group was taken there was an associated vascular injury in 23 (ligation of the main artery of the limb in 19 and of a minor artery, such as the ulnar, in four). The course of regeneration in the non-suture injuries which recovered spontaneously from a state of complete interruption of conduction was, with certain minor differences, much the same regardless of whether or not there was an associated vascular injury. Ligation of the main artery to a limb

introduces such problems as ischæmia in extraneural tissues and the establishment and efficiency of collateral circulations and all that this broad statement implies. A consideration of such problems is beyond the scope of this paper, but as a generalization it may be said that the vascular lesion, at least, does not necessarily impair the course and rate of recovery. This corresponds with the experience of Björkesten (1947), who reported that "the regeneration as such does not seem to be affected by the circulation disturbances due to the vascular injury". Stopford (1920), on the other hand, thought that "ligature of the main artery in the proximal part of a limb may delay and limit recovery", while Geinitz (1920) also holds the view that injuries to blood vessels adversely influence the process of repair.

XX. Influence on the Course of Recovery of a Concomitant Bone Injury.

The extraneural injury was always corrected as fully as possible before nerve repair was undertaken, when any residual offending bony projections received appropriate attention. According to Stopford (1920), "experiences seem to prove that where an ununited fracture of the humerus complicates a musculo-spiral injury it is advisable to treat the bone lesion first".

The presence of a united fracture had no effect on regeneration. The incidence and severity of the bone injury were, however, a useful guide to the severity of the nerve injury. Thus in projectile injuries in which the nerve was severed and the neighbouring bone fractured, the injury to the nerve was usually severe and extensive, or even irreparable. Repair was much more difficult and the end results were consequently poorer. Others have reported that nerve injuries complicated by fractures generally show a poorer result after repair than those in which such complications are absent (Jimeno-Vidal, 1941; Björkesten, 1947).

XXI. Influence on the Course of Recovery of the Use of Sulphanilamide and Penicillin.

Experimental investigations (Holmes and Medawar, 1942; Hammond *et alii*, 1943; Davis *et alii*, 1944) have shown that the local application of moderate doses of sulphanilamide (0·25 to 1·0 gramme) to nerves does not result in any harmful effects, though Hammond *et alii* claim that, if the drug is not rapidly absorbed, it may "offer a mechanical hindrance to the passage of regenerating fibers". Holmes and Medawar observed the interruption of fibres and Wallerian degeneration after the application of large amounts of the drug (2·0 grammes) and conclude that "it should be used with caution at operations in which peripheral nerve trunks are exposed".

Clinical reports suggest that the local use of the drug in moderate doses does not endanger repair (Björkesten, 1947). It was difficult to assess whether or not the application of sulphanilamide powder and/or "Vaseline" had any adverse effect on repair and regeneration, in the injuries investigated, since additional factors influencing regeneration could not be excluded. However, sulphanilamide was used so freely in many cases showing good recovery that it is felt that its use alone could not have had any deleterious effects. Penicillin was instilled into the wound following repair in one case only (Case 137); little recovery resulted, but conditions were so unfavourable for repair that it was not possible to assess the effects of penicillin on regeneration.

XXII. INFLUENCE ON THE COURSE OF RECOVERY OF THE AGE OF THE PATIENT.

With one exception the age of the patients in this series ranged from 19 to 42 years; in the exceptional case the patient was 11 years old. Within this range (19 to 42 years) the age appeared to be without effect on the course of regeneration and the quality of the end result. Two of the best recoveries recorded were observed in patients aged 40 (Case 226) and 41 (Case 166), which is of interest in view of Elkington's (1944) statement that it is doubtful "whether suture of peripheral nerves is of real value after the age of 50". There are not sufficient data in the series to permit a true evaluation of the influence of youth on the course of regeneration and the quality of the end result. The repair in the boy of 11 was followed by a surprisingly good recovery, which far exceeded in quality that reported for any other repair, though it is to be remembered that sensation was not a factor of importance in this case, while local conditions were particularly favourable for repair in that the nerve was cleanly divided, little preparation of the nerve ends was necessary and union was effected within a few hours of the injury. Nevertheless the recovery was so remarkably good as to create the impression that the youth of the patient was a contributing factor. Another case of a young child, not included in this series, in which an immediate repair of the ulnar nerve at the wrist followed a clean laceration, has also shown an exceptional degree of recovery in the entire ulnar field, which exceeds the best recovery observed after the repair of this nerve in an adult. Thus there is some presumptive evidence that the very young enjoy certain advantages which contribute to better recoveries than are observed, other things being equal, after repairs in adults. Others (Souttar, 1945; Zachary and Holmes, 1946) have reported exceptional recovery occurring after nerve suture in the very young, while Platt (1943), Elkington (1944) and Björkesten (1947) include the age of the patient as a factor influencing the end result—favourably in the young and adversely after fifty.

XXIII. INFLUENCE OF MOBILIZATION ON THE BLOOD SUPPLY OF THE NERVE AND ON THE COURSE OF RECOVERY.

The most extensive mobilizations were undertaken in those cases in which the proximal and distal segments of the ulnar nerve were freed while they were bing transposed in front of the medial epicondyle of the humerus in order to effect end-to-end union.

When mobilizing the nerves they were frequently stripped of all surrounding connexions for distances of up to 20 centimetres. Despite this, the trimmed surface of the stumps continued to bleed, though sometimes not as freely as before the separation. Thus, in the material investigated, extensive mobilization failed to arrest the blood flow in the nerve, which was maintained by longitudinal intraneural anastomotic channels. Owing to the many variables influencing the extent and quality of recovery, however, it was not possible to determine whether or not the circulation was disturbed to a degree that would hinder repair and regeneration. In some cases, however, the course of recovery and the quality of the end result indicated that a vascular factor had not been operating to impair the process of recovery.

XXIV. INFLUENCE OF TRANSPOSITION OF THE ULNAR NERVE ON THE COURSE OF RECOVERY.

Transposition of the ulnar nerve was undertaken with the following objects in view: (i) to effect end-to-end suture without tension, (ii) to provide a more satisfactory bed for the suture line when this was situated

at and in the vicinity of the elbow, and (iii) to relieve stretch on the nerve in the full ranges of flexion. Sixteen of the 26 repaired ulnar nerves were transposed. In nine instances of transposition the nerve was left occupying a subcutaneous position, while in seven it was drawn through a tunnel in the common flexor origin; in none of the latter group, however, was the suture line buried in muscle. Following transposition the nerve is stretched with extension instead of flexion of the forearm, but the softer flexor muscle mass has now replaced the firmer bony epicondylar groove as a bed.

In 11 cases transposition was obligatory at the time of repair in order to effect end-to-end union. In five others it was undertaken at a later date in the belief that a retarded recovery might have been due to intermittent stretching and irritation of the nerve in the bony groove induced by forearm movements and of a degree sufficient to impair functional recovery. A study of the course of spontaneous recovery in a collateral series of cases with lesions in continuity provided some presumptive evidence that this factor did delay restoration of function. Since, however, the influence of other variables could not be excluded, it was difficult to assess the value of the transposition of these sutured nerves. The manœuvre did not always lead to an improvement in regeneration, though in these cases the condition had been stationary for some months before transposition was resorted to, and it could be argued that the rerouting might have been more effective had it been undertaken earlier. Furthermore, an improvement in regeneration subsequent to the transposition is no conclusive proof that the manœuvre was a contributing agent, since the retardation or arrest of recovery, for which the transposition was undertaken, may have been due to an entirely different and unrecognized set of factors whose influence was transient and the spontaneous correction of which coincided with the transposition. At least the condition did not regress in any case after transposition, while the frequency with which some improvement followed the procedure strongly suggests that it assists recovery. It is to be noted that the procedure often calls for the sacrifice of the most proximal branch to the *flexor carpi ulnaris*. This results in a paresis of this muscle or paralysis if the branch is its sole source of supply. This should be taken into account when assessing the recovery and evaluating the influence of the transposition.

Conclusion.

From the data provided in this paper there is good reason for believing that transposition, either subcutaneous or through the flexor mass, is not harmful to regeneration; this finding accords with that of Stopford (1920) and Björkesten (1947). There is, on the contrary, some justification for the belief that the procedure assists recovery, though it is impossible to assess the extent of its contribution in this regard. In effecting the transposition it is important to mobilize the nerve above the level where it passes behind the medial intermuscular septum, so that when the nerve is taken anteriorly it ultimately rests not only in front of the epicondyle, but also anterior to the full length of the septum. Unless this precaution is taken, the nerve will be drawn across the edge of the septum as it passes in front of the elbow and will ride across it during movements. Repeated friction or compression over this edge, which may be firm and sharp, may disturb recovery and conduction in the nerve.

XXV. FOR WHAT PERIOD CAN HUMAN MUSCLES REMAIN DENERVATED AND SUBSEQUENTLY FUNCTION ON REINNERVATION?

The findings of this investigation provide some information on the controversial subject of the capacity of human muscles to recover on reinnervation

following prolonged periods of denervation. Much clinical information is already available (for example, Stopford, 1920; Trumble, 1948) to the effect that human muscles, denervated for long periods, do recover when reinnervated, but no details are available as to the extent and quality of this recovery.

The data given in Tables II, V, X and XVI relating to end result assessments of motor recovery have been subjected to a detailed analysis in order to determine the influence of the duration of denervation, and therefore of delayed repair, on the restoration of muscle function following reinnervation. This inquiry is to form the subject of a separate report, but the results may be briefly outlined here. There is no doubt that the earlier the denervated muscle is satisfactorily reinnervated, the better are the chances of recovery. Though delay introduces factors which combine to limit the effectiveness of regeneration, there is no accurate information as to the point at which the changes induced in the muscle by denervation become irreversible. According to Bowden and Gutmann (1944) the biopsy examination of denervated human muscle has shown that "from three years onwards the possibility of any useful recovery is in question". In this inquiry it has been found that very good, if not complete, restoration of function can occur in muscle following periods of denervation of up to at least 12 months, providing that the axons can be directed in sufficient numbers to their original, or functionally similar, end organs, and that the quiescent muscle has been maintained in the best possible condition by appropriate therapy.

XXVI. Course of Regeneration in the Distal Stump following Prolonged Periods of Denervation.

A comparison of the course of regeneration after early and delayed repair (for example, Cases 40 and 166 with 282 and Case 105 with 269) indicates that, after prolonged periods of denervation the distal stump will receive and transmit fibres in a manner that does not differ greatly from that observed when repair is undertaken immediately or shortly after severance. When effecting a comparison of the findings in the two groups it must be remembered that the distances to muscles (measured from a fixed point on the nerve and therefore from the site of injury), together with the initial delay at the site of repair before regenerating axons enter the distal stump, vary from individual to individual and that these variations influence the time of onset of recovery in individual muscles. Nevertheless these variations are not such as to exclude the conclusion that once regenerating axons have entered endoneurial tubes in the distal stump, regeneration follows much the same course after periods of denervation of at least 12 months as after periods of short duration. There is much clinical evidence scattered through the literature on peripheral nerve injuries to support this belief, while Holmes and Young (1942) have shown experimentally that "once within a peripheral stump which has been degenerated for a long time, however, fibres may proceed as rapidly as into a freshly cut one".

Summary.

1. The course of regeneration has been discussed in considerable detail in conjunction with the extent and quality of the final recovery after the end-to-end suture of 59 peripheral nerves. The series comprised 10 cases of suture of the radial nerve, 14 of the median, 26 of the ulnar, and nine of the sciatic and its popliteal divisions. A detailed account has been given of the conditions of the inquiry and the standards of assessment, which are more

precise and comprehensive than any hitherto reported. Details relating to the course of recovery, from the onset of returning function to the final end result, have been provided in respect of each patient. The examinations throughout have been conducted by the same observer. The period of observation exceeded four, three, two and one years in 41%, 32%, 12% and 8% of the cases respectively. A true end result assessment could not be obtained in 20% of the cases because regeneration was still proceeding (7%) or the patient was no longer available for examination (13%).

2. Though each peripheral nerve (for example, radial, median *et cetera*) presents individual peculiarities as regards the course of recovery, the primary object of the inquiry was to establish general principles relating to the repair of severed nerves and to regenerative processes.

3. Special attention has been devoted to a consideration of the factors which influence the extent and quality of the end result. These factors vary considerably from individual to individual, nerve to nerve, and, in respect of certain factors, from level to level along the same nerve. Furthermore, in any case of repair they are so combined that it is difficult, and in most cases impossible, to isolate and investigate each separately so that the full range and scope of the influence which each exerts has not yet been precisely defined.

The impossibility, in the present state of our knowledge, of accurately determining the extent to which each of the participating variables contributes to the residual disability on the completion of regeneration has been discussed, together with the limitations thereby imposed, when attempting an assessment of the influence on the recovery of a particular factor, principle, procedure or technique associated with nerve repair.

4. Observations on the optimum time for repair: (*a*) In lesions in continuity resection of the injured segment and suture are indicated only when signs of complete interruption of conduction prevail for six to nine months. (*b*) A severed nerve should be sutured immediately local conditions are considered favourable for efficient repair.

There is nothing to contraindicate immediate repair when the following conditions are present: (i) The nerve has been cleanly severed and the local tissue damage is minimal and suggests that the residual scarring will be negligible. (ii) The nerve ends can be found easily so that no extension of the wound is required to locate them. (iii) The nerve ends can be securely and easily sutured without mobilization and without tension. (iv) Posture, if required to effect satisfactory union, does not introduce any complications which would adversely influence repair or aggravate scarring. (v) There is no infection.

Secondary repair, which should be performed immediately local conditions are favourable, is indicated when (*a*) the adjacent extraneural tissues are so extensively damaged that involvement of the severed nerve in the subsequent scarring is inevitable; (*b*) it is impossible to assess the full extent of the damage to the nerve; (*c*) there is a loss of nerve tissue with bruising and raggedness of the nerve ends which would necessitate extensive resection and mobilization in order to effect a secure union, and perhaps even then only under tension with the limb adversely postured; (*d*) the wound is infected.

5. Observations on the conditions for resuture:

Resuture should be avoided as long as there is a chance of recovery following the first repair. Delays of seven months would cover all but the exceptional cases, though signs of returning function should be evident by

five months after repair of the median nerve at the wrist. Such delays will not significantly affect the end result if resuture is ultimately required.

The only justification for resuture before adequate time has been allowed for signs of recovery to appear are confirmed disruption at the suture line and when the first suture has been performed under such unfavourable conditions or with such poor technique that little recovery can be expected.

6. The question has been discussed of resuturing nerves that have shown some recovery in an attempt to obtain a better result.

(i) Resuture should never be lightly undertaken for the following reasons: (*a*) there is no guarantee that the patient will fare any better after the second operation; (*b*) the onset of recovery is further delayed; (*c*) the additional resection required leads to a greater dissimilarity in the funicular patterns of the presenting nerve ends, adds to the retrograde neuronal reaction, and introduces another gap, which can be closed only by further stretching of the nerve.

(ii) Further attempts at repair are contraindicated when conditions at the original operation were considered, by one competent to judge, so unfavourable for end-to-end suture that no or little recovery was expected.

(iii) Resuture is indicated when negligible, as opposed to useful, recovery follows a repair in which the technique was faulty, with perhaps some disruption at the suture line, but when prospects for effecting an improved union are good. Negligible recovery also calls for resuture even when the original suture was performed under ideal conditions, since in these circumstances there is nothing to be lost by performing a second repair. The criteria for negligible and useful recovery have been outlined in the text.

7. Observations relating to the technique of repair:

(*a*) Mobilization of at least 20 centimetres of a nerve does not arrest the intraneural circulation and apparently does not adversely affect regeneration after end-to-end union.

(*b*) Unnecessary trimming of nerve ends can be prejudicial to recovery, firstly, by increasing the distance between the nerve ends which should be kept to a minimum so that the measures required to close the gap and permit end-to-end union will not result in harmful tension at the suture site, and, secondly, by increasing the length of nerve destroyed. The most mischievous factors militating against recovery are those that foster the wasteful regeneration of axons into the interfunicular spaces, and these are introduced when there is a dissimilarity of the funicular patterns of the opposing nerve ends. This dissimilarity is increased as the segment of nerve destroyed or removed in the surgical resection increases, and for this reason every attempt should be made to conserve nerve tissue when preparing the nerve ends for repair. The results after the closure of small gaps are distinctly superior to those which follow the closure of large gaps. Great caution must be exercised when examining the trimmed surfaces of the nerve ends to ascertain when morphological conditions are optimal for union, because the amount (in contradistinction to the density) of the intraneural connective tissue together with the number, arrangement and degree of separation of the funiculi are all subject to a wide range of normal variation. Failure to appreciate and recognize this range of normal variation introduces the danger of unnecessarily resecting normal tissue in an attempt to reveal an arrangement which the nerve does not normally show in the involved region.

(*c*) The local application of moderate amounts of sulphanilamide to the wound and the nerve does not adversely affect regeneration after repair.

(*d*) It was not possible to assess the influence on regeneration of the suture materials employed, since other factors that are known to affect recovery could not be excluded. The observations indicate, however, that good recovery can occur when plain black silk and even catgut are used.

8. A palpable bulb beneath a scar on an injured nerve, in which there is complete interruption of conduction, is not necessarily a sign that spontaneous recovery cannot occur, while the absence of a neuroma under the same conditions is no proof that the nerve has not been severed. There was a high incidence of post-operative neuroma formation; the incidence was in fact as high after suture as before.

9. Intraneural damage was proportional to the extent and severity of the injury to surrounding tissues and to the severity and duration of any infection. Intraneural fibrosis appeared, however, to result more from direct trauma to the nerve than from a spreading inflammatory reaction when the wound was infected. The fibrosis may extend further distally than proximally.

The intraneural reaction did not appear to be as extensive or as severe as that reported in material from World War I. Reasons for this are discussed.

The findings suggested that the intact perineurium is particularly resistant to infection and to any surrounding reaction.

A less radical resection than was considered ideal was necessary in many cases in order to avoid a further extension of the gap, which would have rendered end-to-end union impossible. Reasonable recovery, exceeding that customarily observed after grafting, occurred in some of these cases. The advisability is discussed of performing end-to-end suture under conditions that do not appear wholly favourable for repair, in order to provide every opportunity for function to be restored to a stage that would make grafting unnecessary.

10. The consequences of post-operative stretching of sutured nerves have been fully discussed.

Evidence is presented that the tensile strength of the nerve at the suture line is fully restored three to six weeks after repair.

Some degree of post-operative stretching is not necessarily incompatible with a good recovery. Values have been given in regard to the largest gaps, at various levels in various nerves, which have required manipulative procedures to close them and where post-operative stretching has occurred but in which a satisfactory functional recovery has ensued. There is, however, a limit to the size of the gap that can be closed effectively by a combination of mobilization, rerouting and limb posture; furthermore, this limit may be reduced by other factors connected with the injury and the anatomical arrangement of the parts. If this limit is exceeded the nerve ends either cannot be approximated or, if they are, post-operative stretching results in separation at the suture line or the disruption of nerve fibres at levels elsewhere along the nerve.

The critical point at which stretch becomes incompatible with satisfactory regeneration is not yet known, so that it it is difficudt to assess the maximum resection that is compatible with a good functional recovery. In this connexion it should be noted that: (*a*) conduction in a nerve may be impaired by distortion which is insufficient to disrupt the nerve either at the suture line or elsewhere; (*b*) if stretch is very slowly applied the nerve may accommodate itself to the new conditions and function efficiently, whereas sudden stretching is likely to lead to serious consequences either at and/or beyond the suture line. This emphasizes the importance of gradually extending the limb after the latter has been postured to permit end-to-end union.

It is not yet possible to decide confidently whether closure of some large gaps should be attempted by end-to-end suture or by the insertion of a graft. The important factor to keep in mind in this connexion is not the gap that can be reduced without subsequent separation at the suture line, but the gap that can be reduced to permit union which should result in a good functional recovery.

11. Observations on the course of recovery:

Improvement may continue for long periods, but a stationary condition is reached by the fourth year. To take into account this delayed recovery follow-up examinations must be continued for at least three years after repair if the end result assessments are to be reliable.

The early onset of recovery is no guarantee that regeneration will proceed to a satisfactory conclusion, while successful results may follow a delayed onset of recovery. The time at which recovery first appears does not, therefore, provide a reliable guide to prognosis.

The observation that good recoveries may follow a delayed return of function emphasizes the importance of allowing sufficient time for the reappearance of function before contemplating resuture.

The times are given at which signs of returning function can be expected, together with details relating to the subsequent course of recovery, after repair of the various peripheral nerves.

After the repair of median and ulnar nerves signs of cutaneous sensory recovery usually appeared in the hand before the onset of voluntary contractions in the intrinsic muscles of the hand. The reasons for this are discussed.

In the majority of the cases there was either no improvement of joint sensibility or this function remained very defective, even when cutaneous sensation showed a good recovery. This residual sensory defect greatly impaired the usefulness of the motor recovery in the hand.

12. In general, in cases of repair following laceration severance patients fared better than they did when a missile was responsible for the injury. This has been attributed to the following facts:

(*a*) The gaps in the nerve were larger in the gunshot group owing to the greater severity of the causative injury and the more extensive intraneural damage introduced by infection and scarring. This resulted in a greater dissimilarity in the funicular patterns of the nerve ends at the suture line and also necessitated union under tension, both of which reduce the chances of a successful repair.

(*b*) Retrograde neuronal changes are more serious in the gunshot group because of the greater severity of the injury.

(*c*) Recovery in the hand is usually less effective after repair above the elbow. Injuries in the gunshot group predominated at proximal levels and those in the laceration group at more distal levels. The influence of the level of the repair on the course of recovery has been fully discussed.

(*d*) Late sutures are in most cases necessarily delayed because of the presence of associated complications, such as infection and soft tissue and bone injury, so that it is in these cases that the restoration of function is most likely to be impaired by extraneural changes. If the usefulness of regeneration alone is under review, then the influence of the extraneural factor must be excluded.

13. A knowledge of the effect of the interval between injury and repair on the extent and quality of the end result is important for the following two reasons: (*a*) Awaiting signs of spontaneous recovery in lesions in

continuity involves delays of up to six to nine months. Do such delays prejudice the end result if resection and suture are ultimately required? (*b*) Under certain conditions the repair of a nerve that is known to be severed must necessarily be deferred. After what delays are attempts at repair no longer justified?

The findings of this inquiry have demonstrated that:

(i) The capacity of the central stump to regenerate, and the subsequent rate of growth of the regenerating axons, is fully retained for at least 11 months.

(ii) After prolonged periods of denervation (at least 11 months) the distal stump will receive and transmit fibres in a manner that does not differ greatly from that observed when repair is undertaken immediately or shortly after severance.

(iii) Very good, if not complete, restoration of function can occur in muscle following periods of denervation of up to at least 12 months, providing that the axons can be directed in sufficient numbers to their original or functionally similar end organs and that the quiescent muscle has been maintained in the best possible condition by appropriate therapy.

(iv) After delayed repair (11 months) the course of regeneration from onset to termination can follow a pattern that differs in no significant respects from that recorded in those cases in which a successful recovery follows early repair.

(v) Very good recoveries, assessed on a functional basis, can occur after repair which has been deferred for periods ranging from six to eleven months.

14. After high repairs the distal muscles recovered less frequently and, when they did, to a lesser degree than the proximal.

After repair of the median and ulnar nerves at and above the elbow the sensory recovery in the hand was assessed as being of a better grade than the recovery in the intrinsic muscles.

The quality of the sensory recovery in the hand following repair of the median and ulnar nerves at and above the elbow is not as good as that following repairs at the wrist.

Following repair of the median and ulnar nerves at the wrist, sensory recovery in the former exceeded that in the latter.

These observations have been discussed in relation to: (i) the number of nerve fibres innervating each muscle; (ii) the disposition within the nerve, at various levels, of the fibres for individual branches; (iii) the role of individual muscles in executing movements; (iv) the factors determining the appearance of returning function in skin and muscle; (v) the duration of the period of denervation; (vi) the retrograde neuronal reaction, which varies inversely with the distance of the lesion from the cell body.

15. The severity of previous infection and the extent and quality of the residual scarring in the healed wound affect the repair of nerves in two ways: (*a*) By involving the nerve stumps. This means that more extensive resections are required in order to provide "satisfactory" surfaces for union, thereby increasing the gap to be closed and the dissimilarity of the funicular pattern on each side of the suture line, which two factors combine to diminish the chances of a successful repair. (*b*) By affecting the quality of the bed which carries the suture line. The findings in the present enquiry indicate that the former is the more important.

16. Within an age range of 19 to 42 years the age of the patient appeared to be without effect on the course of recovery and quality of the end result. A true evaluation of the influence of youth on nerve regeneration was

impossible since other factors were operating which could not be excluded. There is some presumptive evidence that the very young enjoy certain advantages which contribute to better recoveries than are observed, other things being equal, after repairs in adults. The statement that it is doubtful "whether suture of peripheral nerves is of real value after the age of 50" should be treated with caution in view of the excellent recoveries, reported in this enquiry, following repair in patients aged 40 and 41.

17. The evidence suggests that the following influence the extent and quality of the recovery after nerve suture:

(i) The nature of the causative injury. In cases of repair after gunshot severance progress is not so good as it is following repair performed after laceration severance.

(ii) The level of the repair. Recovery in the hand is usually less effective after repair at and above the elbow than following repair at the wrist.

(iii) The size of the gap to be closed. The results after the closure of small gaps are distinctly superior to those which follow the closure of large gaps.

(iv) Post-operative stretching of the sutured nerve. Some degree of post-operative stretching is not necessarily incompatible with a good recovery. The critical point at which stretch becomes incompatible with satisfactory regeneration is not known. Values are given for the largest gaps, at various levels in various nerves, which have required a combination of manipulative procedures to close them and where post-operative stretching has occurred, but in which a satisfactory functional recovery has ensued.

(v) The age of the patient. There is some presumptive evidence that the factor of age exercises an effect only in favour of the very young.

(vi) Transposition of the nerve. There is some justification for the belief that transposition of the repaired ulnar nerve assists recovery, though it was not possible to assess the extent of its contribution in this regard.

(vii) The duration of the interval elapsing between injury and repair. The evidence suggests that this is not, *per se,* of great significance if repair is not deferred beyond 11 months (the maximum period covered by this enquiry in which a successful recovery followed repair).

(viii) Infection and scarring. These increase the hazards of repair by increasing the length of nerve requiring excision, and therefore the gap between the nerve ends, and by adversely affecting the bed which is to carry the suture line.

18. The evidence suggests that the following are without effect on the course of recovery after nerve suture: (i) A concomitant vascular injury. (ii) A healed fracture. (iii) The local application of moderate amounts of sulphanilamide. (iv) The mobilization of nerves from surrounding tissues for at least 20 centimetres. This does not arrest the intraneural circulation, which is maintained by longitudinal anastomosing channels on and within the nerve.

ACKNOWLEDGEMENTS.

This work was carried out while I was acting as a consultant on peripheral nerve injuries at an Australian military hospital, and the facilities there afforded me by the service authorities are gratefully acknowledged. Particularly am I indebted to the Repatriation Commission (Victorian Division) for the cooperation of its members in permitting the establishment of a follow-up clinic which presented a unique opportunity for maintaining

continuous records. Twenty-eight of the sutures were performed by Major H. Trumble. I was privileged to attend these operations and to assist at most of them, so that the findings at operation are based on personal records. It is a real pleasure to acknowledge my indebtedness to Major Trumble in this regard; his interest in the enquiry and his cooperation throughout have been invaluable. The repairs in three cases (40, 105 and 180) were performed by Wing Commander C. Hembrow, and in two cases (332 and 336) by Major R. Hooper, and to these I am indebted for the detailed records of the operation contained in official files. There was no record of the surgeons responsible for the other operations.

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BIBLIOGRAPHY.

M. Abercrombie and M. L. Johnson: "The Outwandering of Cells in Tissue Cultures of Nerves Undergoing Wallerian Degeneration", *Journal of Experimental Biology*, Volume xix, 1942, page 266.

I. Aird: "The Surgery of Peripheral Nerve Injury", *Post Graduate Medical Journal*, Volume i, Number 2, January, 1947, page 49.

W. W. Babcock: "A Standard Technique for Operations on Peripheral Nerves with Especial Reference to the Closure of Large Gaps", *Surgery, Gynecology and Obstetrics*, Volume xlv, 1927, page 364.

G. Björkesten: "Suture of War Injuries to Peripheral Nerves. Clinical Studies of Results", *Acta Chirurgica Scandinavica*, Volume xcv, Supplement 119, 1947, page 1.

R. E. M. Bowden and E. Gutmann: "Denervation and Re-Innervation of Human Muscle", *Brain*, Volume lxvii, 1944, page 273.

E. E. Cliffton: "Tantalum Foil Cuffs in Peripheral Nerve Surgery", *Surgery*, Volume xxiii, 1948, page 507.

L. Davis, F. Hiller, G. Perret and W. Carroll: "The Effect of Sulphonamide Drugs upon the Regeneration of Peripheral Nerves", *Surgery, Gynecology and Obstetrics*, Volume lxxix, 1944, page 250.

D. Denny Brown and M. M. Doherty: "Effects of Transient Stretching of Peripheral Nerve", *Archives of Neurology and Psychiatry*, Volume liv, 1945, page 116.

J. St. C. Elkington: "Prognosis of Peripheral Nerve Injuries", *Proceedings of the Royal Society of Medicine*, Volume xxxvii, 1944, page 547.

E. Etzold: Quoted by Björkesten.

O. Foerster: "*Handbuch der Neurologie*" (Bumke-Foerster), 1929.

M. Forrester Brown: "The Possibilities of Suture after Extensive Nerve Injury", *Journal of Orthopedic Surgery*, Volume xix, 1921, page 277.

J. Froment and Wehrlin: *Revue Neurologique*, November-December, 1915, page 1233. Quoted by Benisty in "The Treatment and Repair of Nerve Lesions", 1918.

R. Geinitz: Quoted by Björkesten.

E. G. Grantham, C. Pollard and J. A. Brabson: "Peripheral Nerve Surgery. Repair of Nerve Defects", *Annals of Surgery*, Volume cxxvii, 1948, page 696.

L. Guttmann: "Experimental Study on Nerve Suture with Various Suture Materials", *The British Journal of Surgery*, Volume xxx, 1943, page 370.

W. S. Hammond, J. F. Nonidez and J. C. Hinsey: "Effect of Various Sulfonamide Compounds on Nerve Regeneration", *Archives of Neurology and Psychiatry*, Volume L, 1943, page 499.

W. B. Highet and W. Holmes: "Traction Injuries to the Lateral Popliteal Nerve and Traction Injuries to Peripheral Nerves after Suture", *The British Journal of Surgery*, Volume xxx, 1943, page 212.

W. B. Highet and F. K. Sanders: "The Effects of Stretching Nerves after Suture", *The British Journal of Surgery*, Volume xxx, 1943, page 355.

W. Holmes and J. Z. Young: "Nerve Regeneration after Immediate and Delayed Suture", *Journal of Anatomy*, Volume lxxvii, 1942, page 63.

W. Holmes and P. B. Medawar: "Local Application of Sulphanilamide to Peripheral Nerves", *The Lancet*, Volume ii, 1942, page 334.

F. Jimeno-Vidal: Quoted by Björkesten.

W. Lehmann: Quoted by Foerster.

Medical Research Council Memorandum: "The Diagnosis and Treatment of Peripheral Nerve Injuries", 1920.

Medical Research Council War Memorandum Number 7: "Aids to the Investigation of Peripheral Nerve Injuries", 1943.

R. Merle d'Aubigné: Quoted by Björkesten.

E. M. Miller: "Nerve Suture: An Experimental Study to Determine the Strength of the Suture Line", *Archives of Surgery*, Volume ii, 1921, page 167.

H. Platt: "Operations on Nerves", "Modern Operative Surgery", edited by G. Grey Turner, Volume i, 1943, page 475.

H. J. Seddon: "The Early Management of Peripheral Nerve Injuries", *The Practitioner*, Volume clii, 1944, page 101.

H. S. Souttar: "Nerve Injuries in Children", *British Medical Journal*, Volume ii, 1945, page 349.

R. G. Spurling: "Peripheral Nerve Injuries in European Theater of Operations", *The Journal of the American Medical Association*, Volume cxxix, 1945, page 1011.

R. G. Spurling and B. Woodhall: "Experiences with Early Nerve Surgery in Peripheral Nerve Injuries", *Annals of Surgery*, Volume cxxiii, 1946, page 731.

B. Stookey and J. Scarff: "Injuries of Peripheral Nerves", Chapter IV in "Neurosurgery and Thoracic Surgery", Military Surgical Manuals, National Research Council, 1943.

J. S. B. Stopford: "The Results of Secondary Suture of Peripheral Nerves", *Brain*, Volume xliii, 1920, page 1.

J. S. B. Stopford: "Resuture of Peripheral Nerves", *The British Journal of Surgery*, Volume x, 1922, page 216.

S. Sunderland: "Voluntary Movements and the Deceptive Action of Muscles in Peripheral Nerve Lesions", THE AUSTRALIAN AND NEW ZEALAND JOURNAL OF SURGERY, Volume xiii, 1944, page 160; "The Significance of Hypothenar Elevation in Movements of Opposition of the Thumb", *ibidem*, page 155; "The Intraneural Topography of the Radial, Median and Ulnar Nerves", *Brain*, Volume lxviii, 1945, page 243; "Observations on the Treatment of Traumatic Injuries of Peripheral Nerves", *The British Journal of Surgery*, Volume xxxv, 1947, page 36; "Rate of Regeneration in Human Peripheral Nerves: Analysis of the Interval between Injury and Onset of Recovery", *Archives of Neurology and Psychiatry*, Volume lviii, 1947, page 251.

S. Sunderland and L. J. Ray: "The Intraneural Topography of the Sciatic Nerve and its Popliteal Divisions in Man", *Brain*, Volume lxxi, 1948, page 242.

S. Sunderland and K. C. Bradley: "The Cross-Sectional Area of Peripheral Nerve Trunks Devoted to Nerve Fibres" (in preparation).

S. Sunderland and G. M. Bedbrook: "The Cross-Sectional Area of Peripheral Nerve Trunks Occupied by the Fibres Representing Individual Muscular and Cutaneous Branches" (in preparation).

G. Takimoto: "*Ueber die Nervendehnung: Experimentelle und klinische Untersuchung*", *Mitteilungen aus der Medizinischen Fakultät der Kaiserlichen Universität zu Tokyo*, Volume xvi, 1916, page 73.

I. M. Tarlov: "Plasma Clot and Silk Suture of Nerves. 1. An Experimental Study of Comparative Tissue Reaction", *Surgery, Gynecology and Obstetrics*, Volume lxxvi, 1943, page 366; "Plasma Clot Suture of Nerves—Illustrated Technique", *Surgery*, Volume xv, 1944, page 257; "How Long Should an Extremity be Immobilized after Nerve Suture", *Annals of Surgery*, Volume cxxvi, 1947, page 366.

H. C. Trumble: "Nerve Anastomosis in the Treatment of Facial Paralysis", THE AUSTRALIAN AND NEW ZEALAND JOURNAL OF SURGERY, Volume xvii, 1948, page 297.

B. B. Whitcomb: "Separation at the Suture Site as a Cause of Failure in Regeneration of Peripheral Nerves", *Journal of Neurosurgery*, Volume iii, 1946, page 399.

J. C. White and H. Hamlin: "New Uses of Tantalum in Nerve Suture, Control of Neuroma Formation, and Prevention of Regeneration after Thoracic Sympathectomy. Illustration of Technical Procedures", *Journal of Neurosurgery*, Volume ii, 1945, page 402.

B. Woodhall and W. R. Lyons: "Peripheral Nerve Injuries. I. The Results of 'Early' Nerve Suture: A Preliminary Report", *Surgery*, Volume xix, 1946, page 757.

F. Wood Jones: "Voluntary Muscular Movements in Cases of Nerve Lesions", *Journal of Anatomy*, Volume liv, 1919, page 41.

R. B. Zachary and W. Holmes: "Primary Suture of Nerves", *Surgery, Gynecology and Obstetrics*, Volume lxxxii, 1946, page 632.

Case Reports.

HYDATID CYST OF PERICARDIUM.[1]

By K. W. STARR,
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A SOLDIER, A.H.P., aged thirty-four years, was admitted to the Repatriation General Hospital on February 20, 1947, suffering from heart failure.

According to the history he had been well in 1945, but early in 1946 he developed gripping pains in the stomach, not related to food, and dyspnœa on exertion. In March, 1946, he became very ill with severe epigastric pain, tenderness and vomiting, which subsided in about ten days. During January, 1947, he gradually developed swelling of the legs, face and abdomen, and for this he was admitted to hospital.

On examination, all the features of right heart failure were present, the pulse being irregular in tension and amplitude, and the blood pressure was 150 millimetres of mercury, systolic, and 120 millimetres, diastolic. The only positive cardiac findings

FIGURE I. April 29, 1947. Antero-posterior view of the chest, showing the large pericardial effusion.

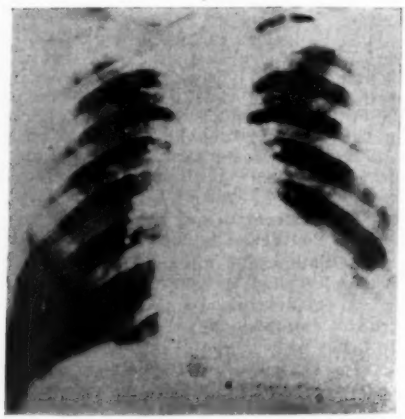

FIGURE II. October 7, 1947. Antero-posterior view of the chest, showing return to normal.

were a large pericardial effusion. The blood count was normal, but on March 13, 1947, an eosinophilia was revealed. An electrocardiographic examination revealed ventricular extrasystoles and myocardial damage.

Because of the persistence of the effusion paracentesis was decided upon. This was performed on March 3, 1947, without difficulty, the fluid showing many erythrocytes, polymorphonuclear cells, a few lymphocytes and an occasional large mononuclear cell; the culture contained *Staphylococcus aureus*, but no acid-fast bacilli. The Casoni test gave a doubtful immediate reaction. The result of the Mantoux test was negative and the blood sedimentation rate showed a fall of 7·0 millimetres in one hour. The results of the Wassermann and Kline tests were negative and the urinary diastase content was normal. The complement fixation test for hydatid disease on May 25 gave a "+++" reaction, and this was confirmed on June 6. There was no evidence of hydatid cyst in lungs or liver, and a barium meal examination showed no abnormal deviation of the œsophagus.

Paracentesis was performed three times during the ensuing three months. Amounts of 45, 20 and 85 ounces were withdrawn without relief.

[1] Accepted for publication on May 17, 1948.

On June 26, 1947, anterior pericardotomy was performed by resecting the third, fourth and fifth costal cartilages and the pericardium was opened. The thick pericardium was, in effect, the wall of a large hydatid cyst which had completely replaced the pericardial sac.

The heart was covered by a necrotic endocyst and the cyst itself contained about 90 ounces of limpid fluid, in which there were a large number of daughter cysts of many generations, varying in size from a tiny marble to an orange. A small nodule, 1·0 centimetre in diameter, was palpable at the atrio-ventricular junction behind, in the myocardium.

The cyst was evacuated, formalinized (which caused some cardiac irregularity), again evacuated and closed.

The patient stood this operation quite well. The left pleural cavity required aspiration for blood-stained effusion on five occasions subsequently.

On August 7, 1947, there was still a considerable amount of fluid present in the pericardium, but there was great subjective improvement, and by October, 1947, there was little abnormal in the chest skiagram.

Comment.

This case is of interest in that most pericardial hydatid infestations are secondary to a primary myocardial involvement. In these circumstances the daughter cysts in the pericardial cavity are usually all of the same age.

Because of the presence of many generations of daughter cysts in the pericardial cavity in this case, it seems very likely that this may have been a primary infestation of the pericardial sac and, accordingly, *rara avis*.

VESICAL FOREIGN BODY: A CASE RECORD.[1]

By V. S. HOWARTH,
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MEDICAL and surgical literature abounds with records of peculiar objects which have from time to time been found in the male and female bladder. The excuse offered for the addition of yet one further to this list is that in this instance the sequelæ are possibly unique and the patient in the course of investigation and treatment passed through the hands of the general surgeon, gynæcologist and the urologist, so that it should be of interest to workers in these surgical spheres.

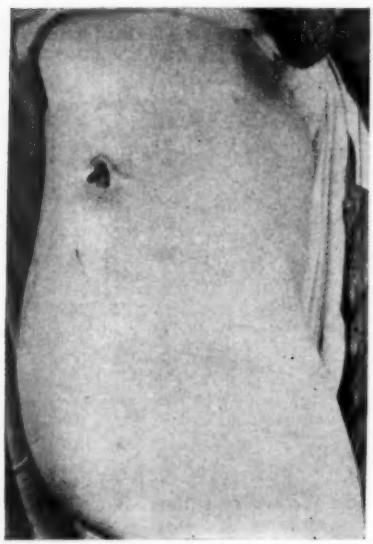

FIGURE I.

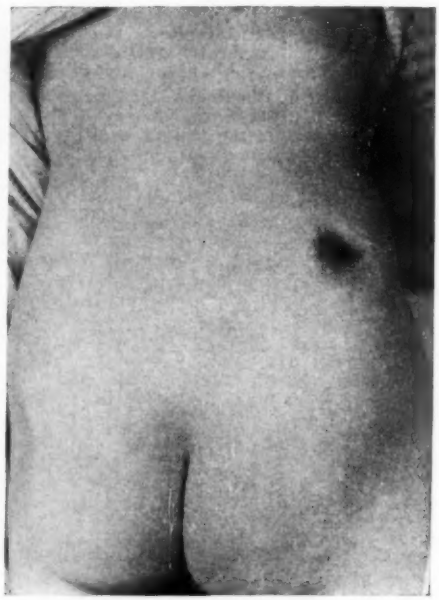

FIGURE II.

It illustrates a series of events which may occur following the introduction of an object into the vesical cavity in the attempt to procure abortion.

In this case the foreign body was introduced into the wrong viscus by an ignorant person. While in the bladder it caused calculus formation, gave rise to symptoms of hæmaturia, frequency and calcaluria, and to profuse pyuria. It ulcerated through the bladder wall into the abdominal cavity, there to produce a phlegmonous inflammation and fistulous communication with the alimentary tract, and its further progress resulted in its appearance on the body surface, giving rise to tumour and then to urinary fistula. In its passage through the abdominal parieties it traversed the well-known lumbar triangle of Petit.

Clinical History.

A female, aged twenty-nine years, reported to the hospital on November 14, 1947. She gave the history of a miscarriage on October 4, 1947, following which she was admitted to a hospital on October 6, 1947, and curettage of the uterus was performed.

[1] Accepted for publication on November 8, 1948.

She was discharged from hospital on October 9, 1947, with instructions to rest in bed for one week, which she did. Her present complaint was of a painful lump in the right side of the lower part of the abdomen, of three weeks' duration, pain in the back of three weeks' duration, and scalding micturition for one week. The case notes at this consultation unfortunately made no reference to the lump of which the patient complained, but when examination of the urine revealed a profuse pyuria and when staphylococci and non-hæmolytic streptococci were recovered in a culture of the urine a provisional diagnosis of pyelitis was made and the patient was treated accordingly.

Her next visit to the out-patient department was on January 5, 1948. The patient's complaints were as before, and the examination notes remarked that a phlegmonous mass was present in the right loin, which showed softening over its centre. The treatment prescribed at this visit was the application of hot packs to the loin swelling.

FIGURE III.

The patient next reported to the out-patient department on April 5, 1948, when interrogation revealed that early in March the swelling in the right loin had come to a head and had discharged copiously. The discharge was foul-smelling, discoloured fluid, which soaked her underclothing, necessitating a change about four times daily. This profuse discharge lasted for about two weeks and gradually became purulent and dried upon the pad which she wore over the fistula. Examination now revealed that the lump noted at her visit on April 5, 1948, appeared as a mushroom-shaped outgrowth with a central sinus one and a half inches long. From a swabbing of the sinus no growth was obtained on culture. The patient complained of burning, scalding and frequency of micturition, and she produced two small stones the size of a pea, which she stated she had passed *per urethram*.

Intravenous pyelography was performed on April 12, 1948, and the report was as follows: "No opacity in the renal or ureteric areas. The films showed normal excretion and no evidence of hydronephrosis. There is an unusual opacity in the region of the bladder, which does not appear to be a vesical calculus, although this cannot entirely be excluded."

The patient was next seen on April 19, 1948, when she stated that she had passed four stones *per urethram* since her last visit. The loin fistula still persisted and had grown deeper. The patient was admitted to hospital and gynæcological examination revealed that on the right-hand side of the lower part of the abdomen, outside the

antero-superior iliac spine and four inches from it, there was a sinus three-quarters of an inch by half an inch, with a tube protruding from it. Pressure on the lower part of the hypogastrium increased the length of tubing which protruded from the sinus. On pelvic examination, palpation of the anterior fornix revealed a tense mobile body.

On April 29, 1948, the patient was transferred to the urological clinic for investigation. Accompanying photographs reveal the state of the patient's abdominal parieties on this occasion (see Figures I and II).

Cystoscopy on April 29, 1948, revealed that the bladder contents were purulent. Tubing could be seen perforating the right superior wall of the bladder. There was a considerable amount of phosphate-encrusted foreign body in the bladder. Cystography revealed a filling defect located in the right superior bladder wall. Plain X-ray examination before and after emptying the bladder of sodium iodide revealed a worm-shaped calcified object (see Figure III).

FIGURE IV.

On April 30, 1948, a ureteric catheter was passed as far as possible along the sinus track into the loin tissues and sodium iodide solution was injected down the catheter. X-ray examination revealed that some of the iodide solution had flowed into the caecum and that some of the medium had outlined loops of small intestine. This examination was repeated on May 1, 1948, with similar findings. During this examination the patient complained of colicky pain referred to the region of the umbilicus (see Figure IV).

Operation.—Under ether anæsthesia suprapubic cystotomy was carried out. The peritoneum was adherent to the pubic bone and was inadvertently opened during the course of the dissection of the prevesical space. The opening was closed by a running suture. A large phlegmonous mass was palpated in the right iliac fossa. The bladder was opened and the foreign body was seen perforating the right supero-lateral vesical wall. The end of the foreign body which occupied the bladder was curled upon itself and heavily encrusted with phosphates. The bladder wall showed surprisingly little inflammatory reaction and the margins of the perforation showed only a little bullous œdema. The foreign body was grasped by means of sponge forceps and made to retrace its passage to the bladder and was delivered through the suprapubic wound. It was followed by a gush of pus into the bladder which was then closed with suprapubic drainage.

Convalescence. The loin fistula healed rapidly. Suprapubic drainage was discontinued after fourteen days and with an indwelling urethral catheter the suprapubic wound healed rapidly. Convalescence was interrupted by the development of a "post-operative chest". The patient's urinary symptoms were completely alleviated and her urine became clear. There were no symptoms referred to the alimentary tract either before or after operation.

The Specimen.

The specimen (see Figure V) was examined by the hospital electrician, who reported as follows: "The object consists of 1·064 gauge braided insulated cable, such

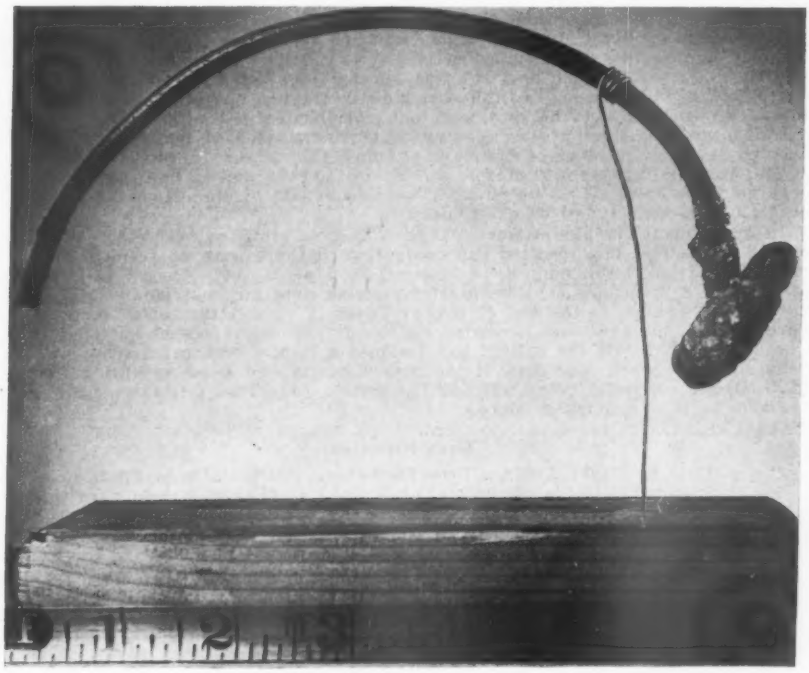

FIGURE V.

as is used for the wiring of electric stoves. It is 13 inches in length. The central cable has been removed from the covering insulation."

Additional History.

On further questioning the patient confessed that the object was inserted on October 2, 1947, in order to procure abortion, when two and a half months pregnant. For this operation a fee of £15 had been paid. Following operation she immediately experienced lower abdominal pain and noticed that her urine was blood-stained. Her medical attendant made arrangements for her admission to hospital, where curettage was performed as noted above.

Acknowledgements.

My thanks are due to Mr. J. W. S. Laidley and Mr. A. Walker-Smith, of the department of urology, Royal Prince Alfred Hospital, Sydney, for allowing me to report this case history, and also to Mr. Paul Trenoweth, of the department of clinical photography, Royal Prince Alfred Hospital, Sydney.

VENOUS THROMBOSIS AT OR NEAR THE THORACIC OUTLET.[1]

By ALAN C. R. SHARP,

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THE object of this paper is to report twelve cases of thrombosis affecting great veins at or near the thoracic outlet and to discuss them with reference to ætiology, treatment and late results. In the detailed accounts of these cases and in the tabular record (Table I) they have been arranged according to ætiology and pathology. In eleven cases the axillary-subclavian segment was affected; the condition was attributable to effort or strain in six cases, two followed indirect trauma, one followed operation, one followed an injection in the arm, and one complicated *phlebitis migrans*. In the remaining case the superior *vena cava* and innominate veins were affected. Treatment varied considerably, because of the stage at which they presented and other factors.

The patients were observed for periods up to five and a half years following discharge from hospital. Nine patients were personally examined, one could not be traced and two were traced by questionary.

In recording the results of treatment the following gradings were used: (*a*) "Excellent", if the patient had resumed full occupation, if there were no residual symptoms and if dilated collateral veins were minimal or absent. (*b*) "Good", if the patient had resumed full occupation, if residual symptoms were minimal (for example, slight ache in the shoulder at the end of a heavy day's work), if there was some residual enlargement of the arm, and if dilated collateral veins were present but smaller than at first. (*c*) "Fair", if the patient had resumed a lighter occupation than previously, if the shoulder ached with use, if the arm, forearm and hand swelled periodically, and if dilated collateral veins were still present. (*d*) "Poor", if there had been no improvement in symptoms or signs.

Case Histories.

Case I. Right Axillary Vein Thrombosis Attributable to Effort.

Fourteen days before his admission to hospital a right-handed male, aged thirty-two years, had lifted a heavy packing case into a lorry and was pushing it forwards along the floor when he felt a slight pain in the right arm and a sensation of "something giving way" in the right axilla. He was able to carry on with his work. The same night small, dilated, superficial veins were noticeable over the anterior surface of the arm, but there was no swelling or pain. Six days before his admission to hospital, while he was using a cobbler's hammer, swelling of the right arm and forearm developed. This increased during the following two days and involved the right hand.

On examination, the patient was a well-developed, healthy, young male with œdema of the right arm, forearm, wrist and hand. There was a collection of dilated venules over the region of the biceps muscle. The superficial veins of the arm, shoulder and right pectoral region were prominent and distended (Figures I and II). The right axillary vein was palpable as a firm cord; it was not tender. There was limitation of movement, with stiffness of the right shoulder. The right arm was larger than the left, the point of maximum difference (4·0 centimetres) being at the shoulder.

Radiographs of the cervical spine did not reveal cervical ribs. The systolic blood pressure was 138 and the diastolic pressure 90 millimetres of mercury in each arm.

Treatment.—A paravertebral block of the right second and third thoracic sympathetic ganglia was performed with 1% "Novocain". The œdema rapidly subsided and after seven days power was good and movements were free, but the superficial veins remained prominent.

Follow-Up.—For two months after the patient's discharge from hospital the shoulder ached and felt weak after use. This quickly improved and at the time of writing, five and a half years later, the patient was employed as a plumber in laying underground cables. His duties included lifting manhole covers and cables and wielding a pick and shovel. The only residual symptoms appeared at the end of a hard day, when there was a "very slight ache" in the right shoulder, which was not quite so mobile as the left. Mild dilatation of the right superficial pectoral veins persisted and the cephalic vein was prominent.

[1] Accepted for publication on September 16, 1948.

TABLE I.

Treatment.

TABLE I.

Case.	Sex.	Age. (Years.)	Diagnosis.	Right- or Left-Handed.	Onset.	Ætiology.	Treatment.						Follow-up Result.[1]	Comments.
							When Begun.	Paravertebral Block.	Anticoagulants.	Elevation.	Massage.	Other.		
1	M.	32	Right axillary vein thrombosis.	Right.	Sudden.	Effort.	14th day	+	−	+	+	—	5½ years later "Good" (Q.).	
2	F.	23	Right axillary vein thrombosis.	Right.	Sudden.	Effort.	14th day	+	−	+	+	Scalenotomy.	6 weeks later "Good."	Radial pulse disappeared on elevation of right arm. Bilateral small cervical ribs.
3	F.	20	Right axillary vein thrombosis.	Right.	24 hours.	Effort.	5th day	+	+	+	+	—	12 months later "Excellent."	Radial pulse disappeared on elevation of right arm.
4	F.	22	Right axillary vein thrombosis.	Right.	Gradual.	Effort.	3½ months	−	+	+	+	Cervico-dorsal sympathectomy.	9 months later "Good."	Both radial pulses disappeared on abducting or elevating arms. Vasospastic attacks.
5	M.	22	Left axillary vein thrombosis.	?	Gradual.	Effort.	21st day	+	−	+	+	—	On discharge "Good" (N.T.).	
6	M.	60	Right axillary vein thrombosis.	Left.	Gradual.	Effort.	6th week	−	−	−	−	Exercises.	12 months later "Fair."	
7	M.	34	Right axillary vein thrombosis.	Right	Gradual.	Indirect trauma.	5th week.	−	−	+	−	Bed for 14 days.	4 years later "Fair" (Q.).	
8	M.	42	Right axillary vein thrombosis associated with ischæmic median nerve paralysis.	Right.	Gradual.	Indirect trauma.	5th month	−	−	−	−	—	3½ years later "Good."	
9	F.	45	Right subclavian vein thrombosis.	?	Gradual.	Thyreoidectomy.	17th month	+	−	+	+	—	2½ years later "Poor."	
10	F.	26	Left axillary, subclavian and innominate vein thrombosis.	Right.	Gradual.	Infection.	2nd day	−	+	+	−	—	1 year later "Excellent."	Consecutive vein thrombosis from left axillary vein.
11	M.	37	Left axillary, subclavian and innominate vein thrombosis.	Right.	Gradual.	*Phlebitis migrans.*	4th week	+	+	+	+	—	6 months later "Good."	Right radial pulse disappeared on bracing shoulders or elevating arm. Consecutive vein thrombosis from left axillary vein.
12	F.	38	Innominate veins and superior *vena cava* thrombosis.	?	Gradual.	Carcinoma of lung.		−	−	−	−	—	Died.	Consecutive vein thrombosis from left innominate vein.

[1] Q. = traced by questionary. N.T. = not traced.

Case II. Right Axillary Vein Thrombosis Attributable to Effort.

Fourteen days before her admission to hospital, a right-handed housewife, aged twenty-three years, was ironing clothes when she suddenly noticed that her right arm felt heavy and that there was bruising on the medial side of the elbow. There was no pain. The patient confided that as a housewife of but one month's seniority she found domestic duties more strenuous than her previous occupation as a factory worker. On the following day the right arm, forearm and hand were swollen and blue. For seven days prior to her admission to hospital she carried her arm in a sling with the elbow flexed to a right angle. For the first few days the swelling increased and the hand became purple in colour. The right shoulder became painful and stiff. Two days before her admission to hospital symptoms commenced to diminish.

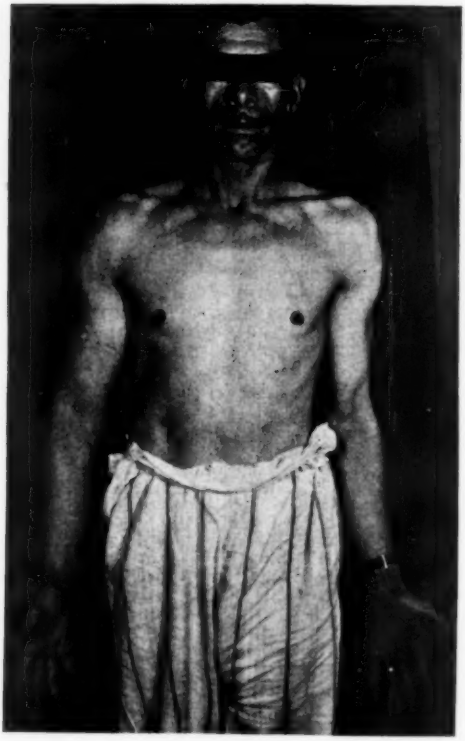

FIGURE I. Case I. Right axillary vein thrombosis. Photograph showing œdema of right arm, forearm and hand, and dilated veins coursing over right shoulder and pectoral region.

On examination there was moderate swelling of the right upper limb. The right hand was cyanosed and cooler than the left. The superficial veins of the forearm, arm and pectoral region were prominent and distended. There was a patch of telangiectases on the medial side of the elbow. The axillary vein was palpable as a hard, slightly tender cord. The right radial pulse was diminished in force compared with the left, and was abolished on elevation of the arm. Abduction of the shoulder beyond 45° produced pain. The blood pressure in the right arm was 141 millimetres of mercury, systolic, and 80 millimetres, diastolic, and 134 and 80 millimetres in the left arm.

Radiographs of the cervical spine revealed bilateral cervical ribs.

Treatment.—The right second and third sympathetic ganglia were blocked with 1% "Planocaine"; this made the hand warm and dry within three and a half minutes. The limb was elevated. On the following day the hand was warm and cyanosis had disappeared. Venous distension of the forearm and hand had subsided, but superficial veins were still visible over the deltoid region. Massage was started. The patient was discharged, symptom-free, after four days' treatment.

In view of the X-ray findings and the effect of posture on the radial pulse the patient was readmitted to hospital six weeks after her discharge. A scalenotomy was performed as a precaution against further episodes of venous or arterial thrombosis. At operation the cervical rib was not exerting pressure on the neuro-vascular bundle, but the right *scalenus anterior* muscle contained tough fibrous tissue near its insertion and this was causing some obstruction of the axillary artery.

Follow-Up.—When seen six weeks after the scalenotomy the patient had been performing housework without difficulty. There was still slight cyanosis of the right hand, and distended superficial veins were still evident on the arm and over the deltoid and pectoral regions, but were reduced in size.

The right radial pulse was still abolished by shoulder retraction and by elevation of the arm above the head. The left pulse was abolished by retraction of the head.

Case III. Right Axillary Vein Thrombosis Attributable to Effort.

Five days before admission to hospital a right-handed female medical student, aged twenty years, was performing unaccustomed physical training exercises (touching toes with extended arms). The next day her arms and shoulders felt stiff and gradually

her right arm became tense, swollen and blue. Tingling of the fingers developed and the hand felt cold.

On her admission to hospital there was an alarming degree of swelling and cyanosis of the entire arm, suggestive at first sight of axillary artery obstruction. However, all pulses were present. The superficial veins of the arm, forearm, hand and right pectoral region were dilated and tense. Radiographs did not reveal any cervical rib. The systolic blood pressure was 120 and the diastolic pressure 80 millimetres of mercury.

Treatment.—The right second and third thoracic sympathetic ganglia were blocked with 10 millilitres of 1% "Novocain" solution and this was repeated on the following day. From the first day of treatment heparin was administered intravenously and the arm was elevated. On the fifth day massage was started.

Follow-Up.—When the patient was seen a year later complete recovery of function had occurred. Except for occasional slight dilatation of the superficial veins of the right hand, both limbs were the same. The radial pulse disappeared on elevation of the right arm above the head.

FIGURE II. Case I. Right axillary vein thrombosis. Photograph showing dilated venules over right arm.

Case IV. Right Axillary Vein Thrombosis following Repeated Strain in a Vasospastic Subject.

Approximately three and a half months before her admission to nospital, a right-handed female nurse, aged twenty-two years, had a wart removed from the left hand. On return to ward duties, which included lifting patients and a heavy sterilizer, she subconsciously saved the left arm. After two or three weeks she noticed that her right arm was beginning to swell and feel heavy. The condition gradually progressed until the swelling was marked and the cyanosis very obvious. In a hot bath the swelling increased and the limb felt painful, with a "bursting hot" sensation. The patient had for some years suffered from frequent vasospastic attacks affecting the fingers of both hands, and usually brought on by cold weather.

On examination there was marked swelling of the right arm and shoulder, which was firm but did not pit on pressure. There was cyanosis of the hand and forearm. The right hand was cooler to the touch than the left. Distended superficial veins were visible on the hand and forearm, in the axilla and over the right pectoral region. A firm, tender cord could be felt in the line of the axillary vein. Tenderness was also present on palpation of the subclavian vessels. On elevation of the limb the right hand became blanched and tingled within a few seconds. The veins of the wrist did not empty readily. On dependency of the limb following elevation a marked and intense hyperæmia of the forearm and hand appeared. The radial pulses disappeared from both wrists on abduction of the shoulders to a right angle and when the patient raised her arms above her head, while she was in the sitting position but not when lying. Radiographs of the cervical spine did not reveal cervical ribs.

Treatment.—Treatment consisted of the intravenous and intramuscular administration of heparin and elevation of the limb. On the third day of treatment massage

was started. Improvement was not maintained and in view of this and the vasospastic attacks a right cervico-dorsal preganglionic sympathectomy was performed.

Follow-Up.—Nine months after her admission to hospital the patient was back on duty at her hospital. The affected arm was slightly larger than the normal one. The hand was warm and dry. The superficial veins were less noticeable, except for an obvious channel which coursed across the posterior wall of the axilla. There was no pain, stiffness or loss of power. The axillary cord was no longer palpable. Except for occasional periods when the veins distended there were no residual symptoms or signs.

Case V. Left Axillary Vein Thrombosis, Probably Attributable to Effort.

Three weeks prior to his admission to hospital an otherwise healthy male, aged twenty-two years, noticed swelling on the inner side of the left arm. His work included lifting heavy objects to waist level and also swinging aeroplane propellers. The next day the left arm, forearm and hand were swollen and bruising was present over the medial side of the arm, which was painful. Conservative treatment (rest in bed with elevation of the arm) had failed to relieve the condition.

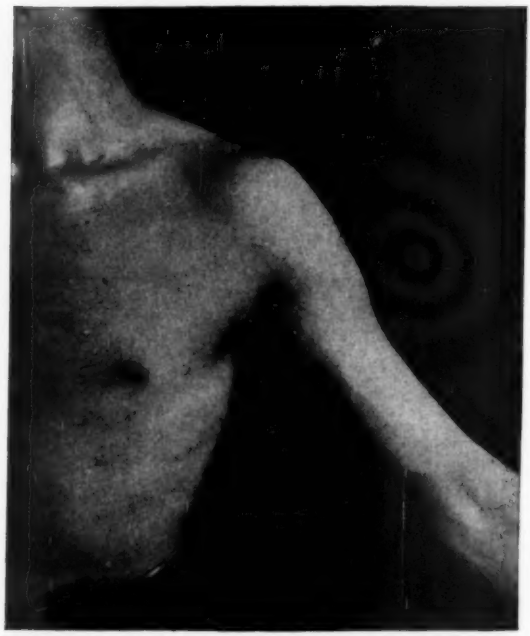

FIGURE III. Case V. Left axillary vein thrombosis. Photograph showing dilated, distended veins over left arm and pectoral region, and coursing over the clavicle to the left external jugular system.

On examination the patient was a well-built young man with generalized œdema of the left arm, forearm and hand. Dilated, distended veins were present over the antero-medial surface of the arm and left pectoral region and drained upwards over the clavicle to the external jugular vein (Figure III). The forearm and hand were reddish-blue in colour. The left hand was cooler than the right, and the skin was thickened and dry. The axillary vein was palpable as a hard, tender cord. The radial pulse was good and unaltered by variations in the position of the shoulder or neck. Radiographs did not reveal a cervical rib.

Treatment.—A paravertebral block produced symptomatic relief, the hand becoming warm and pink within ten minutes of the injection. Elevation and massage were also carried out. Within one week the patient was lifting 25-pound weights without any untoward effects.

Follow-Up.—This patient could not be traced.

Case VI. Right Axillary Vein Thrombosis Attributable to Trauma.

Approximately six weeks before his admission to hospital a gamekeeper, aged sixty years, carried fifteen pairs of rabbits (weight 50 kilograms) by a rope slung over the right shoulder and under the right axilla. After about one mile the shoulder ached with the strain. Three days later the arm, forearm and hand became swollen and dusky in colour and the swelling persisted.

On his admission to hospital the whole arm and hand were larger than the left. Dilated superficial veins were visible coursing over the shoulder and the left pectoral region (Figure IV). A painful thrombosed segment of axillary vein was palpable in the axilla. The right hand was cyanosed.

Treatment.—A course of exercises was prescribed.

Follow-Up.—When seen twelve months later the patient stated that the arm became swollen a little at the end of a heavy day's work and ached occasionally. Otherwise there was no difficulty with work which was not heavy. The numerous small, dilated,

superficial veins seen on the first examination had been replaced by a large, dilated, tortuous cephalic vein which communicated across the floor of the axilla with a vein coursing medially across the chest just above the right nipple (Figure V). The right arm and forearm were larger than the left.

Case VII. Right Axillary Vein Thrombosis Attributable to Indirect Trauma.

Five weeks before his admission to hospital, a corporal, aged thirty-four years (right-handed), serving in a Highland regiment in Normandy, received a glancing superficial gunshot wound of the right fourth intercostal space just above the nipple. For two days he suffered from cold and exposure, until taken to a dressing station. Within three days pain developed in the right shoulder, and three weeks after he was wounded the right shoulder and arm became swollen and the superficial veins of the arm, forearm, hand and the right side of the chest became prominent. There was a dull ache in the shoulder and the arm was dusky blue in colour. The region of the right axillary vein was tender. Two days before his admission the swelling of the arm began to subside. Up to that time treatment had consisted of elevation of the limb.

FIGURE IV. Case V. Right axillary vein thrombosis. Infra-red photograph showing numerous dilated superficial veins sharing venous return.

On examination the right arm was slightly swollen compared with the left. Moderately dilated veins were visible along the medial side of the arm, over the deltoid region and over the right pectoral muscle. There was no colour or temperature difference between the two limbs. The axillary vein was palpable as a firm, tender cord.

Treatment.—The patient was kept in bed for fourteen days and elevation of the limb was maintained.

Follow-Up (by questionary).—Four years after the onset the patient was working as a painter and decorator. During cold weather the arm ached, became swollen, and numbness of the fingers occurred. Dilated veins were still visible on the arm. The residual symptoms were referred mainly to the scar of his gunshot wound, although when carrying things with the affected arm he stated that the grip was poor and the arm ached.

Case VIII. Right Axillary Vein Thrombosis and Ischæmic Median Nerve Palsy Attributable to Trauma.

Five months before his admission to hospital a private in the pioneer corps, aged forty-two years, tripped whilst walking along a dark street and fell forwards on his right elbow and forearm. At once he noticed numbness in the hand and medial three fingers. Next morning there was bruising and swelling of the right elbow and medial side of the forearm. The hand became swollen, cold and bluish-red in colour. A large "water blister" appeared on the dorsum of the hand. Bruising also appeared on the chest wall, just below the axilla. He was treated with fomentations and elevation of the limb. The swelling improved, but the numbness in the digits persisted.

On examination the right and left arms and forearms were equal in size. There was slight but definite distension of the superficial veins of the right arm and right pectoral region. The axillary vein was not palpable. Anæsthesia and analgesia were present in the territory of the median nerve. The muscles innervated by the median nerve were weak but acting. There was a suggestion of thickening on palpation of the flexor muscles of the forearm.

Radiographs of the cervical spine did not reveal any abnormality. A venogram (20 millilitres of 50% "Perabrodil" injected into a cubital vein) showed a localized narrowing of the axillary vein (Figures VI and VII).

Treatment.—No further treatment was considered necessary for the axillary vein thrombosis, as residual symptoms were minimal. It was thought that the median nerve lesion was ischæmic and spontaneous recovery was awaited. The patient was discharged to light duties as a post office sorter.

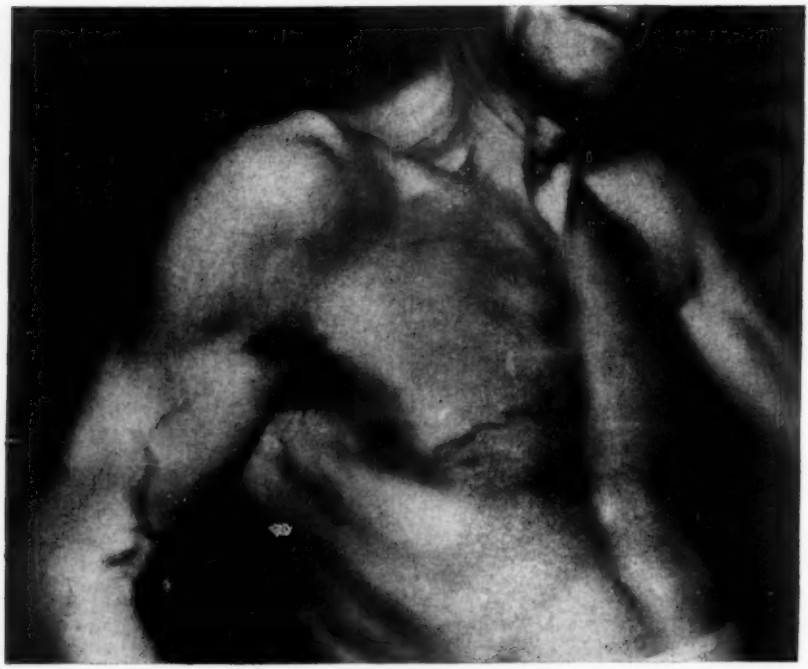

FIGURE V. Case V. Right axillary vein thrombosis. Infra-red photograph twelve mon hs later, showing cephalic vein now serving as main venous channel around the block.

Follow-Up.—When seen three and a half years after the injury he was working as a restaurant car attendant. Superficial dilated veins were still present to a slight degree over the right deltoid and pectoral regions. The recovery of sensory loss in the territory of the median nerve was almost complete. Pain occurred in the right shoulder with use, but was not incapacitating.

Case IX. Right Subclavian Vein Thrombosis following Thyreoidectomy.

One year and five months before her admission to hospital an obese housewife, aged forty-five years, had a thyreoidectomy performed. Soon after the operation she noticed a "tingly sleepy feeling" in her right hand. Three months later the hand, forearm and arm became swollen and at times blue in colour. The hand became discoloured on dependency, but on elevation the swelling subsided and the colour quickly improved. Pain was present in the axilla, shoulder and side of the neck. At times there was loss of power in the fingers. There was no improvement with massage.

On examination the affected arm was seen to be held adducted at the shoulder and flexed at the elbow. Movements at the shoulder were limited and painful. There was gross swelling of shoulder, arm, forearm and hand, but no pitting on pressure. The superficial veins were not very evident owing to the obesity of the limb. There was analgesia to pinprick over the distal two phalanges of all the fingers and distal phalanx of the thumb. On dependency the right hand became cyanosed within four seconds. The systolic blood pressure was 132 and the diastolic pressure 110 millimetres of mercury. Radiographs of the cervical spine did not reveal cervical ribs.

Treatment. — Repeated (three) paravertebral blocks with 1% "Novocain" solution produced temporary relief of pain in the shoulder on each occasion. The colour of the hand became pink. Radiant heat and massage were also employed, but with no marked response.

Follow-Up.—When the patient was last seen, two and a half years after onset, the state of the arm was unchanged. At the time of writing she was awaiting admission for a right cervicodorsal sympathectomy.

FIGURE VI. Venogram of right axillary vein showing a localized narrowing due either to thrombosis or to spasm.

Case X. Left Axillary Vein Thrombosis with Consecutive Thrombosis of Left Subclavian and Left Innominate Veins—Inflammatory in Origin.

A primiparous woman, aged twenty-six years, in the seventh month of pregnancy was admitted to hospital with pre-eclamptic toxæmia. She was delivered of twins, but was critically ill until the eclamptic state had subsided on the fourteenth day, when she noticed stiffness, pallor and swelling of the left hand and arm. There was no pain except for one or two tender areas on both arms at the site of penicillin injections. A day later the swelling spread to include the shoulder, and the left side of the neck became stiff.

On examination the patient was a pale-faced, mentally confused young woman. Intravenous

FIGURE VII. A normal venogram of brachial axillary and cephalic veins. Compare with Figure VI.

drips had been introduced into a superficial vein of the right arm and right leg. There was slight swelling of the lower part of the left side of the face and left side of the neck, but there was no pitting on pressure in these areas. The left external jugular vein was not noticeably distended and there was no tenderness in the supraclavicular region over the subclavian vein. There was œdema of the left arm and forearm, particularly in the most dependent part (the limb was resting on a pillow). The skin over the left shoulder and upper part of the left pectoral region was slightly œdematous. There was a localized area of superficial inflammation at the site of a recent penicillin injection on the outer side of the left arm. Dilated superficial veins were visible over the deltoid region, the left pectoral region and the middle third of the clavicle. Œdema was sufficient to mask any dilatation of the superficial veins of the arm and forearm. A hard, painless cord was palpable in the left axilla in the line of the axillary vein. The left hand was slightly colder to the touch than the right. The temperature chart was of the swinging type. The radial pulses were unaltered by varying the position of the shoulders or head.

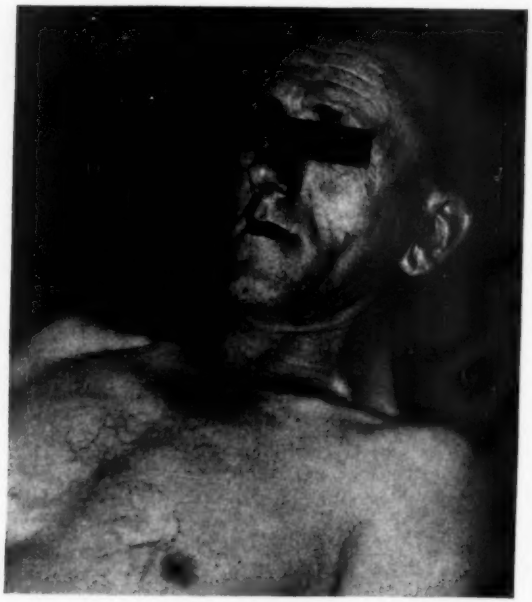

FIGURE VIII. Case XI. Left axillary-subclavian and innominate vein thrombosis. Photograph showing distended external jugular vein.

Treatment.—Treatment consisted of anticoagulant therapy and elevation of the limb (before commencement the clotting time was eight minutes). There was almost immediate improvement of symptoms and rapid reduction in the degree of œdema occurred. The superficial veins became less distended. Within ten days all signs had disappeared.

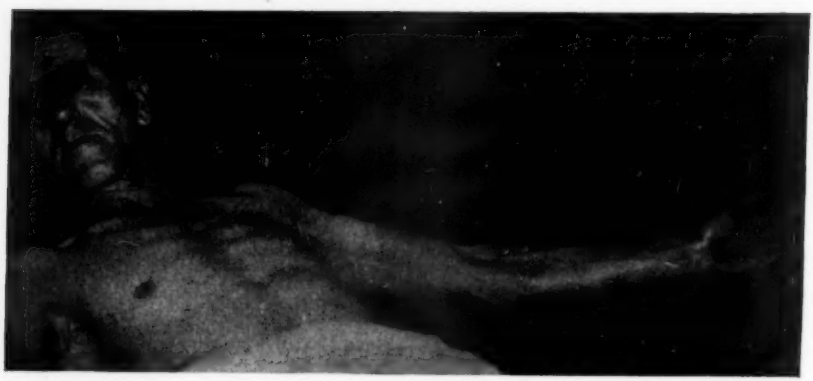

FIGURE IX. Case XI. Left axillary-subclavian and innominate vein thrombosis. Photograph showing distended veins over forearm and hand.

Follow-Up.—When the patient was seen one year later there was complete absence of signs or symptoms referable to the thrombosis. She was living a busy, energetic life, looking after a home, a husband and young twin children.

Case XI. Left Axillary Vein Thrombosis with Consecutive Thrombosis of Left Subclavian and Left Innominate Veins—Inflammatory in Origin.

Four years before his admission to hospital the left arm of a casual labourer (right-handed), aged thirty-seven years, had "become septic" following an inoculation. Two or three months after this he noticed "red blotches" on the dorsum of the left forearm. The skin was raised, reddened and tender. On later occasions his right forearm and right leg were similarly affected. The "blotches" appeared suddenly and usually lasted several days, gradually fading; but occasionally they disappeared suddenly. During this period he was serving in the army; he noticed weakness of the left shoulder during physical training and rifle exercises, and was discharged as unfit. He had lost work periodically because of recurrences of the "blotches" in his arms. For one month before his admission to hospital he had been off work because of increasing general weakness. Twelve days before his admission to hospital the dorsum of his left hand felt painful and rapidly became swollen. During the following days the swelling spread proximally to involve the forearm and hand, which were painful. Three days before his admission to hospital the swelling had extended to involve the left side of the face and neck. There was tenderness in the left posterior triangle of the neck, left axilla, and a tender, reddened area on the medial side of the left arm.

FIGURE X. Case XI. Left axillary-subclavian and innominate vein thrombosis. Venogram showing obstruction at junction of left external jugular vein with innominate.

On examination the swelling and venous distension of the left side of the face had subsided. There was marked dilatation of the left external jugular vein, particularly at its clavicular end (Figure VIII). The vein could be emptied into dilated veins coursing across the clavicle and suprasternal notch into superficial dilated veins visible over the left pectoral region. These in turn drained across the mid-line and downwards towards the line of attachment of the diaphragm. The superficial veins of the left hand and forearm were distended and drained by way of the cephalic vein, which was tense (Figure IX). The basilic vein was felt as a firm, thrombosed cord; its lower end was red and tender. The axillary vein was also palpable as a firm, tender cord. The left hand was slightly cyanosed compared with the right. On the patient's bracing the shoulders back, or when the arm was elevated above the head, the left radial pulse disappeared. The right was unaffected by these manœuvres. The systolic blood pressure was 138 and the diastolic pressure 80 millimetres of mercury in both arms. A venogram made by injecting 20 millilitres of 50% "Perabrodil" into the left external jugular vein, in a clavicular direction, revealed a complete block at its junction with the innominate vein (Figure X).

Treatment.—Treatment consisted of anticoagulant therapy and paravertebral block of the second thoracic ganglion (10 millilitres of 2% "Planocaine"). The block was repeated four days later. On each occasion the block was performed when the clotting time was normal. The limb was elevated on the patient's admission to hospital, and massage was begun on the third day. Within four days of the beginning of treatment there was marked improvement. Pain had disappeared from the axilla and the veins became less obvious.

Follow-Up.—When seen six months later the patient was performing casual labouring duties again. The power of the left arm and shoulder was excellent. There had been no recurrence of "red blotches", no œdema and no pain. The superficial veins were still evident, but less so. In the forearm and arm they were only slightly more obvious than in the right. A large superficial venous channel had replaced in part the smaller ones previously seen over the chest; it coursed across the *pectoralis major* muscle and ended by ramifications at the medial ends of the intercostal spaces. The left external jugular vein was still moderately distended and a dilatation still existed at its lower end. Measurement of the arms revealed no difference in size. It seemed that the innominate and subclavian veins on the affected side were still occluded, but that collateral channels were adequate to deal with the venous return.

FIGURE XI. Case XII. Superior *vena cava* thrombosis. Plain photograph.

Case XII. Superior Vena Cava Thrombosis following Compression by Bronchogenic Carcinoma of the Upper Lobe of the Left Lung.

Four days after an exploratory thoracotomy for inoperable carcinoma of the upper lobe of the left lung, a woman, aged thirty-eight years, developed swelling of the left forearm and hand. The swelling started in the hand and gradually spread proximally, and three days later the left arm and left breast began to swell.

On examination there was œdema of the left arm, forearm and hand, gross œdema of the left breast, with "orange skin" in the dependent part of the breast. There were many dilated superficial veins over the front of both sides of the chest (Figures XI, XII and XIII). The root of both sides of the neck appeared full, but there was no swelling of the face. Both external jugular veins were prominent to the angle of the mandible. Anticoagulant therapy was withheld. During the following days the œdema spread to involve the right arm, forearm and hand and the right breast. At the end of the fourth post-operative week the patient died. Autopsy revealed a bronchogenic carcinoma of the left upper lobe bronchus with widespread metastases. There was compression of the superior *vena cava* and innominate veins by growth. Both innominate veins and the right internal jugular vein were thrombosed.

Discussion.

Thrombosis of the main venous channels at or near the thoracic outlet may be sudden or gradual in onset, may be complete or incomplete in extent, and may affect a small segment or the greater part of the venous pathway from the axillary vein to the superior *vena cava*.

Thrombosis of Effort or Strain (Cases I to VI).—This condition, known to the French as *thrombophlébite axillaire par effort*, was the subject of a review by Matas (1934). It is a disease which affects (most commonly) the right arm of healthy young right-handed men.

In this series the sexes were equally affected. The patients were all young, excluding the patient in Case VI (aged sixty years), and all were otherwise healthy.

In the majority of cases the diagnosis is self-evident. There is a history of an accident, an injury by strain, or there has been repeated occupational muscular strain (Cases IV and V). According to Matas (1934), there is a rare group of cases in which axillary thrombosis develops suddenly and spontaneously without any apparent cause. Either at once or a few hours or days following the injury or strain, there develop swelling and cyanosis of the entire arm with dilated superficial veins of the affected limb and over the corresponding pectoral region. The hand is cold and there is pain in and immobility of the shoulder. Pitting œdema may be detected, but much of the swelling is firm and brawny. In most cases the axillary vein is palpable as a tender, thrombosed cord.

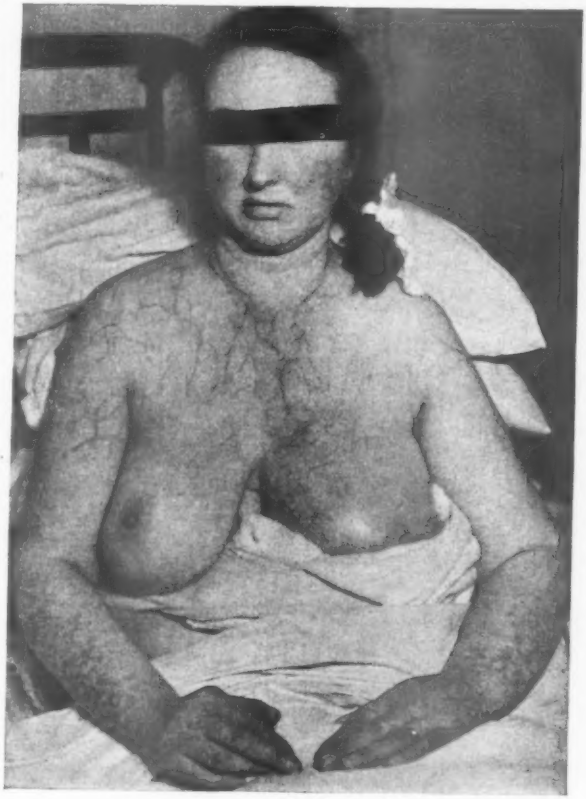

FIGURE XII. Case XII. Superior *vena cava* thrombosis. Photograph taken with an orange filter.

A venogram (20 millilitres of 50% "Perabrodil") may help to determine the degree and site of organic obstruction, but is not advisable in the acute stage. Infra-red photography is useful in revealing superficial veins which are otherwise invisible. Pictures taken at intervals give a fair indication of the progress of the condition (Figures IV and V).

The manner in which the axillary (or subclavian) vein is injured is still debatable. As a result of anatomical researches, Lowenstein (1924) claimed that trauma of the vein is the main cause of localized phlebitis and that this is brought about by overstretching and contusion of the vein between the clavicle and the first rib or between the costo-coracoid ligament and the subclavius muscle. Gould and Patey (1928) injected plaster of Paris into the axillary veins of post-mortem subjects and concluded that the subclavius muscle is responsible for the pathological lesion, by causing rupture of the delicate subclavio-axillary valve which underlies that muscle. Lahaussois (1910) suggested as factors, first, a respiratory effort distending the vein and, secondly, an injury to the endothelium by overstretching and compression.

Intermittent obstruction of the subclavian vein is, on rare occasions, the result of pressure by the *scalenus anterior* muscle. It may be associated with and attributable to a cervical rib. Barker (1948) quotes a case in which scalenotomy led to relief of symptoms. In Case II of this series a cervical rib was present, but apparently not a

causative factor. The scalenotomy was performed as a precaution against further episodes of venous or arterial thrombosis.

It seems reasonable to suppose that the type of person liable to thrombosis of effort would be the young, energetic, well-built person whose radial pulse in one or both arms disappears with variations in the position of the shoulder or neck. In this series disappearance of the radial pulse during these tests was noted in Cases II, III, IV and XI.

Leriche (1927) held the view that venospasm is the cause of the œdema and venous obstruction. He maintained that, as the result of trauma or strain, vasomotor reflexes are set up in the perivenous sympathetic plexuses. Venous thrombosis then occurs and maintains the spasm. For this reason he advised excision of the injured segment. According to Matas (1934), a condition may develop in the arm, clinically identical with thrombophlebitis of effort, in which a careful dissection and exposure of the axillary vessels reveal no lesion whatever, not even venospasm, and only a trauma of the adjoining muscles. Figure VI shows a venogram in a case of axillary vein "thrombosis" with localized narrowing suggestive of venospasm.

FIGURE XIII. Case XII. Superior *vena cava* thrombosis. Infra-red photograph.

If such disordered vasomotor changes occur in the veins, it seems surprising that evidence of associated arterial spasm was not observed. In Case VIII, which was attributable to indirect trauma, there is evidence suggesting that a period of arterial spasm may have occurred; but this was not found in any of the cases of thrombosis attributable to effort.

The ætiology of venous thrombosis of effort is still obscure. The multiplicity of hypotheses suggests that it may be the result of a combination of factors. The present state of our knowledge appears to be much the same as it was fourteen years ago, when Matas concluded that "so-called 'axillary thrombosis by strain or effort' is a complex syndrome of polyvalent causation, in which indirect trauma of the axillary vein and its immediate environment, including the lymphatics and perivenous sympathetic plexus, plays the leading role, and that thrombosis is the usual but not an essential or obligate feature of the lesion".

Thrombosis Attributable to Indirect Trauma.—Two cases in this group occurred in the axillary vein. The first patient (Case VII) was admitted to hospital five weeks after the onset. No specific treatment was instituted because the condition was then subsiding. Unfortunately this patient could not report for examination and the follow-up information was obtained by questionary. Although he still complains of residual symptoms, the fact that he is employed as a painter and decorator suggests a good

return of function. The second patient (Case VIII) is of interest because he is the only one of the series who could be considered to have associated brachial arterial spasm. The only evidence of this was the existence on his admission to hospital of a median nerve palsy and contracture of the flexor muscle mass of the forearm, for which no other explanation could be found. The spasm must have been temporary, as the pulses were all present when the patient was examined.

Case IX is unusual in that a right subclavian vein thrombosis followed thyreoidectomy. The patient reported for treatment seventeen months after the onset. There has been no improvement in the symptoms and signs for two and a half years. The clinical picture in this patient was complicated by the presence of hypertension and obesity. There was also a considerable psychological overlay associated with a complete lack of willlingnes to use the affected arm for even the lightest duties. Her poor general muscle tone and the continued immobility of the shoulder and arm were in themselves sufficient cause for at least a proportion of the cyanosis and swelling.

Thrombosis Attributable to Infection.—This occurred in two patients. In one (Case X) the spread of infection occurred by way of the superficial veins from the site of a penicillin injection in the arm. In the other (Case XI) *phlebitis migrans* appeared to be the causative factor; as an additional predisposing factor, narrowing of the thoracic outlet on the affected side was suggested by the disappearance of the radial pulse when the patient braced the shoulder or elevated the arm. Both these patients presented an interesting feature in that consecutive thrombosis had spread to involve the subclavian and innominate veins on the affected side. Such extension of thrombosis may occur in a proximal or a distal direction and may occur rapidly, as in the first case, but it can be checked by the institution of anticoagulant therapy. In both cases the condition responded well to this form of treatment, and since discharge from hospital there has been no recurrence of *phlebitis migrans* in the second patient.

Treatment and Results.

In the acute stage of axillary vein thrombosis the treatment recommended consists of anticoagulants and elevation of the limb. This may be supplemented by a paravertebral sympathetic block (1% "Novocain" or 1% "Planocaine" solution) of the second and third sympathetic ganglia on the affected side. In four cases of this series heparin was employed for periods varying from four to seven days, according to the time taken to obtain the maximum improvement in symptoms and signs. Supplies of anticoagulants were not always available; other patients were seen too late for this form of treatment to be of value. The dose varied according to the response in the clotting time taken one hour after administration. The aim was to obtain an increase of the clotting time to twenty minutes or over. The usual initial dose was 10,000 international units given intravenously, followed by 7,500 units every eight hours. Experience with these and other vascular conditions has shown that the intramuscular route may be used when the intravenous method is difficult or inconvenient. The dose is the same and is administered every eight hours. It is advantageous because of the ease of administration, but the effect on the coagulation time is less certain.

Provided adequate anticoagulant therapy is instituted early in the acute stage, recovery will be rapid and convalescence correspondingly shortened. Residual disability both as regards signs and symptoms should be minimal. Excellent results were obtained in Cases III and X, in which treatment was started within five days of the onset of thrombosis; the response was quite dramatic. Experience with these two cases demonstrated that at this early stage obvious clinical improvement occurs within a few minutes of a paravertebral injection of "Novocain", or within thirty minutes of the first intravenous injection of 10,000 international units of heparin. The colour of the hand can be seen to improve, it becomes warm, the engorgement of the superficial veins diminishes, and pain and stiffness are relieved.

The response to anticoagulant therapy is too rapid to be explained only by the removal of preformed clot or by the prevention of consecutive thrombosis. It may be due in part to the relief of venospasm permitting the maximum use of main or collateral channels.

Excision of the affected segment of vein is not recommended because, as has been suggested, the obstruction may be due to spasm and not to thrombosis. The exact location may be difficult to define, and any operative intervention must inevitably damage or destroy useful venous main or collateral channels.

Massage of the affected limb and shoulder should be started on the second or third day of anticoagulant therapy. Once the acute stage of thrombosis has been controlled, treatment should be directed towards any other contributing factor—for example, costo-clavicular pressure, pressure by the *scalenus anterior* muscle or by a cervical rib. In cases of chronic obstruction it may be necessary to provide a two-way stretch elastic support to aid the venous and lymphatic return.

Summary and Conclusions.

1. Twelve cases of thrombosis affecting great veins at or near the thoracic outlet are reported.

2. In eleven cases the axillary-subclavian segment was affected, and in one the superior *vena cava* and innominate veins. These are discussed with reference to ætiology, treatment and follow-up results (Table I).

3. In the acute stage of thrombosis of the axillary-subclavian segment the importance of early adequate anticoagulant therapy, paravertebral block and elevation is stressed.

4. Excision or thrombectomy of the affected segment of vein is not recommended.

5. After the acute stage has subsided, attention should be directed towards the relief of any aggravating or contributing factor, such as costo-clavicular pressure, *scalenous anterior* pressure, or pressure by a cervical rib.

6. The best results were obtained in those cases in which early adequate treatment was instituted. It appears from the present series that when treatment is instituted before the fifth day of the disease (axillary-subclavian thrombosis), the thrombotic process is probably reversible. The superficial veins became normal or were reduced in size, suggesting that venospasm had been overcome and that recanalization of the segment had occurred. The condition of patients coming for treatment after the fourteenth day of the disease was improved, but the collateral venous channels remained distended. This suggests that the process was by this time irreversible and recanalization of the affected segment did not occur.

Acknowledgements.

In all the cases reported the patients were treated by Professor J. R. Learmonth, to whom I am very grateful both for the opportunity to study them and for encouragement and help in the preparation of this paper.

I wish to acknowledge also the kind assistance of Dr. C. C. Burt, Dr. R. L. Richards, and the staff of the department of surgery of the University of Edinburgh.

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Bibliography.

E. V. Allen, N. W. Barker and E. A. Hines: "Peripheral Vascular Disease", 1946.

N. W. Barker: "Axillary Thrombophlebitis Caused by Strain or Effort", *Proceedings of the Mayo Clinic*, Volume x, 1935, page 156.

E. P. Gould and D. H. Patey: "Primary Thrombosis of the Axillary Vein: A Study of Eight Cases", *The British Journal of Surgery*, Volume xvi, 1928-1929, page 208.

M. Lahaussois: "*Thrombo-phlébite traumatique aseptique*", *La presse médicale*, Volume xviii, 1910, page 410.

J. R. Learmonth: "Some Sequels of Abnormality at the Thoracic Outlet", *Thorax*, Volume ii, 1947, page 1.

R. Leriche: Quoted by R. Matas, *loco citato*.

P. S. Lowenstein: "Thrombosis of the Axillary Vein: An Anatomic Study", *The Journal of the American Medical Association*, Volume lxxxii, 1929, page 854.

R. Matas: "On So-Called Primary Thrombosis of the Axillary Vein Caused by Strain: Report of Case with Comments on Diagnosis, Pathogeny and Treatment of this Lesion in its Medico-Legal Relations", *The American Journal of Surgery*, Volume xxiv, 1934, page 642.

Reviews.

Outline of Physiology. By Wm. R. Amberson, Ph.D., and Dietrich C. Smith, Ph.D.; Second Edition; 1948. Baltimore: The Williams and Wilkins Company. 10″ × 6¾″, pp. 514, with 193 illustrations. Price: 37s. 6d. (Australian currency) net.

"Outline of Physiology", by Amberson and Smith, is in fact an outline of physiology. It starts off with the physiology of cells and the relationship to their environment. It then deals with the peculiar structures and behaviour of cells. Having completed this section, the authors then deal with the physiology of the systems of the body. At all stages they have carefully calculated their starting-off point so that obscurities are avoided. The exposition then takes the reader up to conceptions which are based upon the latest possible experimental results. This exposition of subject matter is well combined with an account of the development of knowledge and the persons responsible; occasionally significant investigators are overlooked, but generally this is a most excellent feature of the book. It is, however, curious that, having managed this so well, the authors give no bibliography whatever. An outline of physiology is an introduction to the science of physiology and should introduce people to the important original texts in the subject.

The book is well illustrated with diagrams in colour, line and tone by the late Norris Jones and William Loechel, and they are very good indeed. They are artistically satisfactory and there has been no compunction in reducing the conceptual content to the simplest and most significant features.

The set-up of the book is good and the fount suitable for the purpose, but with the copy submitted for review the real fault in the printing was that the glue had not been confined to the places where it would be useful; when spread between printed pages it can be annoying.

The generally eulogistic remarks on this book must not be taken to indicate that there are no weaknesses in it. With such a book the authors cannot go into alternative hypotheses fully; as a consequence the full range of speculation in the subject is not covered. In other cases there are slight inconsistencies from one part of the book to another. Any faults in these respects are, however, much less than in most other books, especially those written by a group of authors. Indeed, this book is a very good argument for making provision for two or three excellent expositors to have the necessary relief from other duties to allow them to produce a book which has a consistency of scientific outlook from beginning to end.

Medullary Nailing of Küntscher. By Lorenz Böhler, M.D.; translated by Hans Tretter; 1948. Baltimore: The Williams and Wilkins Company. 10″ × 6¾″, pp. 398, with 1261 illustrations. Price: 52s. 6d. net.

This book is the English translation of the third volume of Böhler's well-known book (1944 German edition) on fractures and is interesting as a careful and balanced study of this unusual method of treatment. It appears that medullary nailing is extensively used in Europe by many surgeons for all closed fresh fractures—often compound also—of the shafts of long bones, providing that the fracture is transverse and situated in the middle third. It is used as an alternative to external splinting and the justification for this policy is that the nail is introduced into the bone at a distance from the fracture site and consequently the danger of infection is slight. In this country, however, surgeons nearly always expose the fracture site. The nail is not advised for children in whom non-union or limitation of knee movements is a rarity, especially as they are susceptible to severe surgical shock after operations on the femoral shaft. Böhler believes that the main indication for the nail is in fresh fractures of the middle third of the femur because it helps to avoid the limitation of knee movement which is so common after external splinting, but this advantage is lost if open reduction is used for the insertion of the nail. It is inadvisable for the radius and ulna. In the humerus and tibia two nails are required because of the size of the expanded medullary canal in the proximal ends; but the guiding principle according to Küntscher and Böhler is the avoidance of open reduction—that is, exposure of the fracture site. This is possible by threading the nail through the two fragments after an exact reduction has been obtained by an assistant with a complicated reducing apparatus and repeated fluoroscopic examination has been made at short intervals with two X-ray units, "without which medullary nailing is absolutely impossible". Open reduction and

medullary nailing for mal-union and non-union *et cetera*, for which there are not the same objections to open nailing as in recent fractures, is carefully dealt with. The indications and technical difficulties are clearly described in the greatest detail. There are throughout the book repeated warnings of the many dangers, especially death, which is caused by shock if operation is too prolonged in recent injuries. The list of complications is formidable and is stated to be increasing with further use of the nail. The author has performed a duty that his responsible position in fracture treatment has imposed on him, in his plain counselling and warnings. All surgeons who use or contemplate trying this method should arm themselves by a study of this important, critical and complete analysis.

Correlative Neuro-Anatomy. By JOSEPH J. MCDONALD, M.S., M.Sc.D., M.D., JOSEPH G. CHAROID, A.B., M.D., and JACK LANGE, M.S., M.D.; Fourth Edition; 1948. California: University Medical Publishers. 10″ × 7″, pp. 156. Price: $3.00.

THIS little book is a synopsis of neurological anatomy, neurological physiology and the diagnosis of neurological disorders. In the compass of 156 pages the authors have presented and correlated the essential information contained in some of the best and most up-to-date works on clinical neurology, neuro-anatomy, neuro-radiology, neuro-pathology and neuro-physiology. References are given to the works consulted.

Excellent black and white line drawings illustrate the text. The book is light, with a flexible cardboard cover. The loose pages, whose surfaces are dull and whose print is very clear, are held together by an effective form of plastic material. This production, therefore, is comparatively cheap and easily handled. Within its scope the book provides a remarkable fund of well-ordered information not accessible in any other single work. It should be of particular value to students, especially post-graduate students, and to clinicians.

Text Book of Anæsthetics. By R. J. MINNITT, M.D. (Liverpool), D.A. (R.C.P. and S. England), and JOHN GILLIES, M.C., M.B., Ch.B. (Edinburgh), F.R.C.S. (Edinburgh), D.A. (England); Seventh Edition; 1948. Edinburgh: E. and S. Livingstone. 8½″ × 5½″, pp. 576, with 229 figures. Price: 30s. (Sterling).

THE latest edition of this well-known text-book has been enlarged and revised. It represents what may be termed the modern conservative outlook of British anæsthetic practice, both new and outmoded techniques being faithfully dealt with. The fundamentals of anæsthesia are satisfactorily covered, though the authors' attitude to shock and its prevention might not be approved by many surgeons.

There are good descriptions of the construction and use of several gas machines, and useful accounts of local anæsthetic procedures.

This is a book for the inquiring graduate rather than the student, because the section on the signs of anæsthesia, as in most text-books, is the least enlightening.

Treatment by Diet. By CLIFFORD J. BARBORKA, M.D., F.A.C.P.; Fifth Edition; 1948. Philadelphia: J. B. Lippincott Company. Pp. 802, with 14 plates (13 in colour). Price: 75s. (Australian currency).

CLIFFORD J. BARBORKA'S fifth edition of "Treatment by Diet" is divided into four sections: Part I, "Diet in Health"; Part II, "The Application of Diet Therapy"; Part III, "Diet in Disease"; Part IV, "Routine Hospital Diets: Pre-Operative and Post-Operative Dietary Management".

The book has been brought up to date throughout. The section on diet in health has been concisely and well written. It includes a brief account of methods of diagnostic aid in determining deficiency states.

Most of the book is devoted to a consideration of diet in disease. A feature of this section is the clear method of setting out details of diets. The practitioner who is not very familiar with the calculation of dietetic requirements of patients will find these tabulated diets of great practical value.

Although the title of the book is "Treatment by Diet", the author does not confine his writing to diet only. Other therapeutic measures are freely discussed and in a helpful manner. However, one therapeutic measure of doubtful value was noted on page 101. Referring to diabetic coma, the author states: "In case the patient is unable

to swallow, 15 Gm. of pure dextrose in a 5 per cent. solution are given every three hours by retention enema." This measure is surely of little value. It has been demonstrated that the absorption of glucose from a retention enema is negligible.

It is a volume to be thoroughly recommended to the medical profession and it is splendidly produced by the J. B. Lippincott Company.

Human Neuro-Anatomy. By OLIVER S. STRONG and ADOLPH ELWYN; Second Edition; 1948. Baltimore: The Williams and Wilkins Company. 10" × 6½", pp. 452 with 336 figures. Price: 45s.

THE author of any text-book must inevitably give some thought to those who will eventually read his work, and the form which the book takes will be profoundly influenced by these considerations. Those concerned in writing a text-book of human neuro-anatomy have three main fields of interest: the student, the academic anatomist and the practising physician and surgeon. The interest of the student lies mainly in structure, the anatomist is interested mainly in teaching methods or in new information from which further investigations may be initiated; for the clinician there are different viewpoints. For accurate diagnosis and localization of lesions of the central nervous system an intimate knowledge of structure in relation to function in both normal and disease processes is required, but in addition to this knowledge the surgeon requires accurate anatomical knowledge of the relations concerned in the surgical access to various regions within the central nervous system. The anatomical factors which control the spread of infections have attained peculiar significance in these days. The author will be confronted with a difficult task if he endeavours to embrace all these interests. This task is not made easier by the fact that it is so often necessary to relate structure to function; so that much of what is written may be found in the equivalent manual of physiology. Thus it has become almost the rule to find post-graduate neuro-anatomy mixed with physiology of the standard taught in the preclinical years.

Thus it would appear that the time has arrived when neuro-anatomy must be rendered in a medium more suited to the individual requirements of sections of the medical profession. In "Human Neuro-Anatomy" the authors have enlarged on the physiological aspects of the subject, and frequent reference is made to the clinical effects of isolated lesions of the structures described; but there is little to help the surgeon in planning operative procedures, and little coordinated description of such important areas as the cerebello-pontine angle or the suprasellar region.

The first chapters deal with the development and organization of the central nervous system, and a clear, concise and readable description is found. In general, insufficient attention is given to those mechanisms in default of which the various congenital abnormalities of the nervous system are produced. At a time when much work is being expended on the surgery of developmental defects and in the investigation of intrauterine disease, it is surprising to find developmental abnormalities dealt with in such a summary fashion. The chapters on the histology of the neurons and interstitial tissues are accompanied by well-chosen diagrams and photomicrographs and fill a real need.

The authors have dealt with peripheral and segmental innervation at some length, in response, no doubt, to the recent increase in interest in peripheral nerve injuries arising in the war and also to recent problems associated with sciatica and brachial neuritis. Indeed, a knowledge of dermatome distribution is essential in all spheres of clinical medicine at the present time, when many of these conditions have their origin in nerve root compression or irritation. The organization of the sensory pathways in the spinal cord is admirably described, but here again the clinician finds difficulty in the discontinuity of description, for the chapters are confined to segments of the central nervous system, so that it is impossible to obtain a complete survey of the sensory pathway without reference to more than four separate chapters.

Another source of dissatisfaction for the clinician is the apparent lack of balance in subjects of interest. The anatomy of the autonomic system is dismissed in sixteen pages, and although the description of the distribution of the ganglia and fibres may be adequate, little space is given to their relations to other structures. In fact, the surgeon will obtain little help in his dissections of these structures. On the other hand, the internal structure of the pons is described in great detail and occupies thirty-seven pages. More adequate descriptions of the anatomy of the autonomic system are justified at the present time, when extensive operative procedures are being carried out with great frequency and enthusiasm.

The description of the brain stem, basal ganglia and hypothalamic regions is still based on the customary description of cross sections, but the descriptions are well coordinated and frequent reference is made to clinical implications. Functional considerations are given in detail and form an interesting background to the anatomical organization of areas like the hypothalamic region.

In the preface to this edition the authors state that the chapter on the blood supply of the brain has been made more complete, but once again it is regretted that the common variations have been omitted. A further and more serious omission is a clear description of the subarachnoid spaces and the anatomy of the ventricular system. It would seem that the anatomist, instead of providing data for the clinician to work on, is being left behind by new methods of investigation. Arteriography, encephalography and ventriculography are being used more and more, and the clinician is accumulating more facts concerning normal variations and anomalies which appear unknown to anatomists. At the most they receive scant attention.

In their preface the authors state that they are attempting to "link structure and function in a dynamic pattern without sacrificing anatomical detail", and for the most part this must be conceded. As a basis for diagnosis and localization of lesions of the nervous system the scope of the book would appear to be excellent for the honours student and those engaged in post-graduate work. For the surgeon there remains a real deficiency in the omission of what might be termed surgical neuro-anatomy.

Recent Advances in Surgery. By HAROLD C. EDWARDS, C.B.E., M.S., F.R.C.S.; Third Edition; 1948. London: J. and A. Churchill, Limited. 8″ × 5″, pp. 447, with 131 illustrations. Price: 24s. (Sterling) net.

MR. EDWARDS has sought and achieved a praiseworthy definition of recent advances in surgery. This is an excellent, almost an indispensable, book and bridges with astonishing completeness that rather broad gap between textbook and modern practice. Where so much of modern surgery has been included, and where such a balanced high standard has been maintained, it may appear unreasonable to expect more.

Perhaps the modern approach to fractures (the wider use of plating and intramedullary fixation), tendon surgery (especially in the fingers) and that increasingly important surgical field the use and indications for the free and pedicled skin grafts could have been included. Nerve suture and grafting would have been worthy of mention.

No post-graduate student or active surgeon will wish to be without a copy of this careful and accomplished review of recent surgical advances.

Gastritis. By RUDOLPH SCHINDLER, M.D., F.A.C.P.; 1947. London: Wm. Heinemann (Medical Books) Limited. 9″ × 5¾″, pp. 474, with 96 illustrations. Price: 50s. net.

IN 1922 Dr. Schindler published his first article on gastroscopy. His studies started in 1920 and since then he has published many important observations on gastroenterology. This book is based on more than 2,500 cases diagnosed as gastritis.

The book is divided into pathological and clinical sections and an attempt has been made to correlate clinical, gastroscopic and pathological findings. At times the effort seems Procrustean.

The extremely divergent views advanced on the subject of gastritis in the last forty years or so are evidence of the inherent difficulties in presenting views which are generally acceptable. The limits of altered function, clinically, gastroscopically and pathologically, are difficult to define. Thus the subheading to the photomicrograph on page 368, which reads "The surface epithelium is rather normal", illustrates some of these difficulties. It can be appreciated that, if the interpretation of carefully collected biopsy material should present such difficulties, how much greater is the assessment of subtle mucosal changes as seen through the gastroscope. Moreover, the vastly superior optical qualities of Hermon Taylor's gastroscope over those of the Wolf-Schindler instrument have revealed that changes previously considered to be due to gastritis are due to artefacts.

The book is well illustrated by photomicrographs, photographs of gross specimens, and gastroscopic views in colour. There is a 30-page summary of 55 selected cases of gastritis. The bibliography of 401 references adds to the value of the book.

Whatever one's views, the book is an emphatic statement presented with much skill, and it contains the conclusions of a man who has devoted nearly thirty years of intensive study to the subject.

The Essentials of Modern Surgery. By R. M. HANDFIELD-JONES, M.C., M.S., F.R.C.S., and A. E. PORRITT, C.B.E., M.A., M.Ch., F.R.C.S.; Third Edition; 1948. Edinburgh: E. and S. Livingstone, Limited. 9¼″ × 5½″, pp. 1276, with 644 figures. Price: 50s. (Sterling) net.

WITH the ever-increasing span of surgical knowledge most textbooks of surgery have suffered enlargement to at least two volumes. It is therefore of considerable interest to teachers and students to read in the preface to the third edition of this book the editors' restatement of their basic principle to produce a single volume textbook in which the teaching is based on surgical principles. These principles are supported by modern application, such as recent chemotherapeutic and operative methods.

There are a few improvements which could be made for Australian standards of teaching, such as the omission of the ancient Biers suction cup (Figure I), more emphasis on the saline treatment of burns and better illustrations of blood transfusion apparatus. It is astonishing to read that actinomycosis can be cured by X-ray therapy. It is time that surgical textbooks referred to primary and secondary "closure" of wounds instead of "suture" of wounds. Closure may be by suture, but should be by skin grafting when suture is impracticable.

This textbook can be strongly recommended for undergraduates.

Books Received.

"Medical Research in War" (Report of the Medical Research Council for the Years 1939-45); April, 1948. London: His Majesty's Stationery Office. 9″ × 6″, pp. 456. Price: 7s. 6d. net.

"A Primer in Clinical Science." By R. Douglas Wright; 1948. Melbourne: Melbourne University Press. 8¼″ × 5¼″, pp. 43. Price: 3s. 6d. net.

"The 1947 Year Book of Pathology and Clinical Pathology." Edited by Howard T. Karsner, M.D., and Arthur H. Sanford, M.D.; 1948. Chicago: Year Book Publishers, Incorporated. 7″ × 4½″, pp. 558, with 103 figures. Price: $3.75.

"The Treatment of Malignant Disease by Radium and X-Rays, Being a Practice of Radiotherapy." By Ralston Paterson, M.C., M.D., F.R.C.S.E., D.M.R.E., F.F.R.; 1948. London: Edward Arnold and Company. 9½″ × 6¼″, pp. 632, with numerous illustrations. Price: 45s. net.

"The 1947 Year Book of General Surgery." Edited by Evarts A. Graham, M.D.; 1948. Chicago: Year Book Publishers, Incorporated. 7″ × 4½″, pp. 734, with 200 illustrations. Price: $3.75.

"Encyclopedia of Medical Sources." By Emerson Crosby Kelly, M.D., F.A.C.S.; 1948. Baltimore: The Williams and Wilkins Company; 1948. 9″ × 5¾″, pp. 476. Price: 56s. (Australian currency).

This is essentially a dictionary of eponyms and a most valuable reference book.

"Laboratory Technique in Biology and Medicine." By E. V. Cowdry; Second Edition; 1948. Baltimore: The Williams and Wilkins Company. 9″ × 5¼″. pp. 296. Price: 30s. (Australian currency).

A reference book listing short descriptions of techniques with references to the literature as well as eponymous references.

"Source Book of Orthopædics." By Edgar M. Bick, M.D., F.A.C.S.; Second Edition; 1948. Baltimore: The Williams and Wilkins Company. 9″ × 5¾″, pp. 552, with 31 figures. Price: 60s. (Australian currency).

A fascinating account of the development of orthopædics throughout the ages, followed by a review of the parts played by the application of physiology, morphology and pathology in the development of contemporary orthopædic surgery. Each chapter carries a large bibliography.

"The Practice of Chiropody." By Keith Campbell Jones; 1948. London: Angus and Robertson, Limited. 9¾″ × 6″, pp. 288, with 23 figures. Price: 42s. (Australian currency).

"Minor Surgery." By R. J. McNeill Love, M.S. (London), F.R.C.S. (England); Third Edition; 1948. London: H. K. Lewis and Company, Limited. 7¼″ × 5¼″, pp. 438, with 221 illustrations. Price: 22s. 6d. net.

"The Rh Blood Groups." By P. L. Morrison, A. E. Mourant and R. R. Race: Medical Research Council Memorandum, Number 19; 1948. London: His Majesty's Stationery Office. 9¼″ × 6″, pp. 74. Price: 1s. 6d. net.

"A Short Practice of Surgery." By Hamilton Bailey, F.R.C.S., and R. J. McNeill Love, M.S. (London), F.R.C.S.; Eighth Edition; 1948. London: H. K. Lewis and Company, Limited. Part I, 8¼″ × 5¼″, pp. 246, with 259 illustrations (89 coloured); Part II, 8¼″ × 5¼″, pp. 428, with 271 illustrations (81 coloured). Price: 52s. 6d. (Sterling) net for set of five. (Parts not sold separately.)